A PLAIN and FAMILIAR

INTRODUCTION

TO THE

NEWTONIAN EXPERIMENTAL

PHILOSOPHY;

In SIX SECTIONS,

Illuſtrated by SIX COPPER-PLATES.

Deſigned for the Uſe of ſuch

GENTLEMEN and LADIES

As would acquire

A Competent KNOWLEDGE of this SCIENCE, without Mathematical Learning;

And more eſpecially thoſe who have, or may attend the

AUTHOR's COURSE

OF

LECTURES and EXPERIMENTS

On theſe Subjects.

By BENJAMIN MARTIN.

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INTRODUCTION
TO THE
PHILOSOPHY

BRITISH MUSEUM

THE PREFACE.

THE conſtant Importunity of many of my Auditors to draw up ſuch an Introduction to Philoſophy, as might prepare them to underſtand the ſeveral Subjects of my Lectures and Experiments; and when theſe are over, to refreſh their Memories, and revive and fix in their Minds the fleeting Ideas of what they had then heard and ſeen, is the Reaſon of the preſent Publication. I have alſo taken care to oblige them in another

Reſpect

Reſpect, and that is, to compriſe the Whole in ſo ſmall a Compaſs, as to put them to very little Expence, either of Time or Money, to acquire a very conſiderable Knowledge of all the principal Branches of this moſt valuable and delightful Science; which by this Means will be rendered of great Service to improve the Mind, and embelliſh it; but without the Aſſiſtance of ſuch a Treatiſe, it cannot be regarded as any thing more than a polite and rational Amuſement.

And not only ſuch as attend the Lectures, but any Gentleman or Lady, who is happy enough to have a Taſte for Knowledge of the beſt Sort, will find this ſmall Tract give them as little Trouble in the Purſuit and Acquiſition of it, and at the ſame time entertain them with as great a Variety and Novelty as they can poſſibly expect. When they underſtand what they here find (for which nothing more than a common Capacity and a little Attention is neceſſary) they may have Recourſe to Books of a higher Claſs; but, if they have not Mathematical Learning,

Learning, *they must be content to understand Philosophy in that Way only which is here taught*, viz. *By observing the Phænomena of Nature, and deducing from thence their Causes, which are rendered general by a just Method of Reasoning, and proved to be real by Experiments. And this is sufficient for Mankind in general.*

I shall not here say any thing to recommend the Study of this Science, having already done that in another Piece *. *And that nothing may be wanting to facilitate the Reader's Progress in Philosophical Enquiries, I have embellished and illustrated the Whole by six Copper Plates, representing the principal Experiments in each of the Lectures; and also added a copious Index of all the principal Matters, and accented all the Words for rightly pronouncing them. Also all hard or technical Words are thoroughly explained; and I have taken all the Care and Precaution I possibly could, to remove every thing that might in the least tend to retard the Reader, or render this noble and divine Science less amiable to his View.*

* A PANEGYRIC on the *Newtonian* PHILOSOPHY.

To conclude, I must advertise the Reader, that those Propositions, which admit of or require Mathematical Demonstration, *are here put into* Italics, *and may be found so demonstrated in my* Philosophia Britannica, *a Second Edition of which has been lately published in Three Volumes Octavo.*

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A Plain and Familiar

INTRODUCTION

TO THE

Newtonian Experimental Philoſophy.

SECTION I.

PHYSICS.

Containing a Deſcription of ſuch INSTRUMENTS, PREPARATIONS, *and* EXPERIMENTS *as explain and illuſtrate the* POWERS *of* ATTRACTION *and* REPULSION; *the* PROPERTIES of natural BODIES, *the* PRINCIPLES *of* Mechanic Arts, Chemical OPERATIONS, *Nature of* METEORS, *Doctrine of* VEGETATION, MAGNETISM, *&c.*

THE Deſign of this Courſe of Experimental PHILOSOPHY is to exhibit, in a very natural and eaſy Manner, the principal and moſt important *Phænomena* or Appearances of natural Bodies; to account for their *Cauſes* and *Effects* on plain

and evident Principles, and to prove and illuſtrate the ſame by a great Variety of curious and new-contrived Inſtruments and Experiments; ſo as to render the Whole not only the moſt *rational and inſtructive*, but alſo the moſt *pleaſant and ſatisfactory Entertainment*.

2. The Subject of the preſent Lecture are thoſe *Powers* of *Nature* which may be juſtly eſteemed the *fundamental* Principles of all *natural Philoſophy*; to ſhew the Plate 1. Reality of their Exiſtence, their ſeveral Properties and wonderful Effects, and to apply the ſame towards ſettling a juſt Theory of *Chemiſtry*, the *Animal Oeconomy*, *Vegetation*, the Nature of *Meteors*; together with the *principal Properties* of the *Magnet*, and its Uſe in *Navigation*.

3. This Power affects all the Particles of Matter, and acts upon them in a two-fold Manner, *viz.* 1. By cauſing them *to accede to, or approach each other*; and becauſe in this Reſpect they ſeem to *draw each other mutually*, it is called the *Power of Attraction*. 2. By cauſing thoſe Particles, in ſome Circumſtances, *to recede, or fly from each other*, it is called *Repulſion*, or a *centrifugal Force*.

4. But this Power is in itſelf *one and the ſame*, and only acts in this *different Manner* in *different Diſtances* between the Par- Fig. 1. ticles. Thus a Piece of Iron, touched with the Magnet, held near one End of a Magnetic

Magnetic Needle, will *attract it*; but applied to the other End, it will *repel it*. So the ſmall Particles of Matter being nearly in Contact, ſtrongly *attract* each other, and *cohere together*; but being ſeparated by the Action of Heat, or otherwiſe, they repel and fly from each other, as is evident by many Experiments.

5. Now to ſhew that the *Repulſion* of one End of the Needle is not a Conſequence of Attraction in the other, as ſome pretend, I take a Needle, one half Braſs and the other Iron, and the ſame End is repelled in this as in the common Needle, which Experiment plainly ſhews this Repulſion is *real* and *poſitive* between the two Bodies. Fig. 2.

6. And further, it appears by Experiment, that the ſame End of the Needle, which is *repelled in one Diſtance is attracted in another nearer Diſtance*. And hence it follows, that there is a certain near Diſtance in which the Particles of Matter attract each other; and which is therefore called the *Sphere of Attraction*; beyond which the ſaid Power acts *by Repulſion*; and ſo where *Attraction ends* there *a repulſive Power commences*.

7. This *attracting Power* may be conſidered as affecting immediately the original Particles of Matter, and by that means cauſing them to adhere or cohere firmly together, and ſo qualifying them to form larger Portions of Matter, or Bodies of different Degrees of

Conſiſtence, and hence it is uſually called the *Attraction or Power of Coheſion.*

8. But when we conſider this Power in the large Parts or Portions of Matter, as the aggregate or united Force of all the attracting Forces of the component original Particles, it is then called the *Power of Gravitation*, as in the Sun, the Earth, and other planetary Bodies of the mundane Syſtem. Becauſe any ſmall Bodies near the Surfaces of thoſe larger ones, are ſtrongly *attracted towards their Centers*; which *Tendency* thereto is in thoſe leſſer Bodies called their *Weight* or *Gravity*.

9. This *Power of Coheſion* is directly demonſtrated by the Experiment of *two leaden Balls* or *Bullets*, having their Surfaces made very plain and ſmooth, and gently preſſed together, do cohere ſo very faſt and firmly, as to require the Weight of many Pounds to ſeparate them. Particularly two of a larger Sort are ſhewn by the Steel-yard to require not leſs (ſometimes) than two hundred and fifty Pounds Weight to pull them aſunder, which ſhews plainly the prodigious Force by which they adhered together, eſpecially if it be conſidered that the whole Area of their Contact or Surface, by which they touched, does not exceed a twentieth Part of a ſquare Inch. Hence no Part of this Coheſive Force can be imputed

Fig. 3.

to

to the *Preſſure of the Air*, which will be hereafter ſhewn to be but fifteen Pounds upon a whole ſquare Inch.

10. But to reduce to a Calculation this wonderful Power of Nature, by an Experiment, I take a Piece of Braſs Wire, $\frac{1}{32}$ of an Inch in Diameter, and applying it to the Steel-yard, there is required ſixty Pounds to pull it aſunder; from whence, and the given Area of the Wire, it will be found that the Force of Coheſion in the Surface of a whole ſquare Inch of ſuch Braſs will be at leaſt equal to ſeventy-ſix thouſand four hundred Pounds, or thirty-five Tons Weight nearly.

11. That this Power acts *only on Contact* of the Particles, or at Diſtance *indefinitely ſmall*, is evident from many Experiments, particularly thoſe of *Trituration*, or reducing Bodies to *Powder*; for by this Means ſeparating the Particles, they loſe their Coheſion inſtantly; thus all Sorts of Grain are reduced to *fine Flour*; and the hard fixed Body of Glaſs is by this means reducible to a *fluid impalpable Powder*.

12. Again, this is further evident by Experiments of a contrary Kind, *viz.* by re-compounding and uniting the fractured Parts of Bodies by the Interpoſition of ſome Kinds of Matter, which ſhall fill up the Pores of the Powder, and bind them by this attracting Power into conſiſtent and ſolid maſſes

again. Thus Water unites the Parts of Flour into Dough and Bread, and the looſe duſty Earth into hard *Clods* and *Bricks*.

13. This leads us to conſider the Nature of *Cement* in general, which in every Kind affords moſt wonderful Inſtances of this ſurpriſing Power. It is well known, that in all hard Bodies, whoſe Parts cannot be brought to touch each other intimately by Preſſure (as in the leaden Balls) the Interpoſition of ſome other Body or Matter is neceſſary to cauſe an Adheſion between them; and this interpoſed Matter, which thus binds the Bodies together, is called a *Cement*, or, in the metallic Kind, *Solder*.

14. Hence it is that all poliſhed Planes, as Glaſs, Marble, Braſs, &c. are made to adhere together, by only wetting their Surfaces with *Water*; but this Coheſion will be much ſtronger if Oil be uſed inſtead of Water; and ſtronger yet with *Suet* or *Tallow*. In all theſe Caſes, if the Planes be heated ſo that the *Oil* or *Tallow* may *freely enter the Pores*, and thereby more intimately unite with them, the Coheſion will (with Tallow) be ſo very great, that in two Planes, whoſe Surfaces are but *one ſquare Inch*, there is required two hundred Pounds to ſeparate them in very cold Weather, as is ſhewn by Experiment. So wonderfully great is this Power in leſs than *half a Grain of Tallow*,

15. The

15. The Nature of *Glues* is from hence evident alſo; for when thoſe *viſcid* Subſtances are liquified by Heat, they enter the Pores of Wood, *&c.* and two ſuch Pieces being applied together, and the humid Part of the Glue evaporated, they are by the Remainder attracted, and made to adhere very firmly.

16. Thus alſo, if *Iſinglaſs diſſolved in Brandy* (which makes the ſtrongeſt Glue) be poured on the Surface of any Medal, and left to dry on it, there will be formed a moſt curious *Lamina*, containing the moſt *perfect Impreſſion of the Medal*; in itſelf tranſparent; but may be covered with Gold or Silver, as ſhewn in the Experiment.

17. The Method of *foliating Glaſs* proceeds on the ſame Principle; for Quickſilver poured on *Leaf Tin*, will intimately unite therewith, and make a fluid Surface; upon which, if a Piece of clean Glaſs be laid, the Mercury will alſo enter its Pores, and *thus unite or cement the Tin to the Glaſs*, and ſo convert it into a very uſeful *Speculum* or *Looking-glaſs*, as is ſhewn by Experiment.

18. In *metalline Bodies*, that are to cohere by *Solder*, it is neceſſary that the Parts to be ſoldered ſhould firſt be well-cleanſed, that when the Metals are heated, and the *Solder* melted, it may in that fluid State run freely into the Pores on each Surface, and thereby take the more firm hold of them,

and when hardened with Cold, may bind them with a prodigious Force together. To illuſtrate this by Experiment, I take a Piece of Braſs well cleanſed, and putting a few Grains of Mercury upon it, rub it all over the Surface with a Piece of Cork, which will thereby become ſilvered throughout; and two ſuch Pieces put together by their ſilvered Surfaces will cohere; and could the Quickſilver be in this Caſe fixed as melted Metals are by Cold, this would prove *a Solder like any of them*; and therefore *fully explain the Rationale of this Proceſs*.

19. By many Experiments it appears there is between different Kinds of Bodies a different Power of Attraction between their conſtituent Particles. Thus, when *Water is put into a Glaſs*, it is ſeen to riſe all round by the Side, which it could not do if the Particles of the Water were not attracted more by the Glaſs than by each other. For it is eaſy to underſtand if the Particles of Water next the Glaſs were attracted on each Side, or every Way equally, *they could not move at all*, much leſs could *they riſe upwards*, contrary to their own *natural Tendency or Gravity*.

20. On the other Hand, if *Mercury* be put into a Glaſs, the Surface of it is lower all round by the Sides than in the Middle, which ſhews that the Parts of Mercury are more attracted by themſelves than by the Glaſs, becauſe, were they equally attracted by

by the Glaſs, they would be on every Side equally attracted, and conſequently the Surface would be every-where even or plane.

21. On this Principle it is eaſy to account for the Riſing of Fluids in *Glaſs Tubes* with ſmall Bores, called *Capillary Tubes*. For ſince the Water within the Tube is ſolicited upwards by a ſuperior Attraction (*Art.* 19.) it will riſe in the Bore ſo far till the Weight of the Cylinder thus raiſed *is equal to the Exceſs of the attracting Force*, and then there it will ſtand continually. This is all evident by Experiment.

22. Since this Power *acts only upon Contact* (*Art.* 11.) the Water can be affected only by thoſe Particles of the Glaſs that are contiguous to them above the Surface, and therefore *only by a Circle of Particles* equal to the Circumference of the Bore of the Tube; and therefore, ſince all Effects are proportional to their Cauſes, the *Quantities of Water raiſed in Tubes of different Bores muſt neceſſarily be in Proportion to the Circumferences*, * *or to the Diameters of thoſe Tubes.*

23. Hence if the Diameters of the Bores of two Tubes, A and B, be as 2 to 1, the Quantity of Water raiſed in A will be twice as great as that raiſed in the Tube B; but the Height of that in B will be double the Height of the Fluid in A; becauſe the Quantity of the Fluid in A, is Fig. 4.

to

to that in B, of the ſame Height as four to one (* *being as the Squares of their Diameters)* therefore half the Quantity in the Tube B muſt have double the Height of that in A; and hence univerſally, *the Heights to which Fluids will riſe in capillary Tubes, will be always greater in proportion as the Diameters of the Tubes are leſs.*

24. And as the Water *riſes* in theſe Tubes, ſo *Mercury* will ſtand in them *below* the common Level of that without; and theſe Deficiencies will be greater, as the Diameters of the Tubes are ſmaller, for the Reaſons before-mentioned (in *Art.* 20.) which is alſo evident by Experiment.

25. From hence alſo we ſee the Reaſon why *all Fluids riſe ſo readily into Sponge, Sugar, Sand,* &c. to very great Heights; becauſe there is a much greater Force of Attraction between the Particles of theſe Bodies, and thoſe of the Fluids, than there is between the Parts of the Fluids themſelves.

Fig. 7. 26. Hence alſo we have the *Reaſon of the Operation of the capillary Siphon* CD, which raiſes Water thro' one Part by Attraction, and carries it over the bended Part into the longer Leg, where it deſcends by its Weight and drops out.

Fig. 7. 27. This accounts for *the Nature and Action of the Filtre* AB, the moſt ſimple of all the chemical Inſtruments. For as this is made by ſmall Pieces of *Linen or*

Woollen Cloth, Yarn, Thread, &c. the ſeveral Filaments attract the Fluid in the ſame Manner as the *capillary Siphon,* and carry off the Fluid *Drop by Drop.*

28. And indeed *all the more conſiderable Operations of Chemiſtry* are explicable upon this moſt ſimple Principle. Thus in the *Solution of Bodies* in various Fluids or *Menſtruums,* nothing is required more than a greater attracting Force between the Particles of the Fluid and the Solid, than there is between the Particles of the Solid themſelves; and therefore, when the ſolid Body is immerſed in the Fluid Menſtruum, thoſe Parts which are in immediate Contact with the Fluid, muſt neceſſarily loſe their own Coheſion, and be ſeparately attached to the Particles of the Fluid; and ſince this will be the Caſe continually, till every Particle of the *Menſtruum* has attracted and Fig. 5. united to itſelf ſo many of the Solid as it can ſuſtain, the Solid will by this Means continue to be diſſolved for ſome time, *viz.* till the whole Medium is ſaturated therewith, and then the Solution ceaſes. All which is manifeſt by Experiments of any *metalline Bodies, Mercury, Chalk,* &c. put into *Aqua Fortis, Spirit of Nitre, Vinegar,* &c.

29. In Solutions of this Kind, ſeveral Things offer themſelves very well deſerving our Notice. As *that moſt, if not all, hard and fixed Bodies are by this means reducible*

to

to a State of Fluidity. That the heavieſt Bodies, as Gold, Mercury, &c. *are hereby ſuſpended in Fluids many Times lighter than themſelves. That the moſt opake Bodies, as Mercury,* &c. *may, by having their Parts thus attenuated, be rendered moſt tranſparent and pellucid,* &c. &c. &c.

30. In this Proceſs of Nature we may obſerve, the Action between the Fluid and ſolid Body is much more intenſe and violent in ſome Caſes than in others; thus *Aqua Fortis* attracts the Particles of *Braſs* much more ſtrongly than thoſe of *Lead* or *Tin*; and the Parts of *Iron*, with much greater Violence than thoſe of *Braſs*; and in Proportion as this inteſtine Action of the Parts is greater, there will be produced a greater Degree of *Heat* in the Solution, attended with a ſtrong *Ebullition*; and upon a Mixture of ſome *eſſential Oils*, this Commotion of the Parts will be ſo ſudden and violent, as inſtantly to cauſe a *real Accenſion*, or pure Flame to riſe; which fully confirms Sir *I. Newton*'s Doctrine, *that all Degrees of Warmth, Heat, Fire, and Flame, are ſolely produced by various Degrees of the inteſtine violent Motion of the Parts of Bodies.*

31. If the *Menſtruum* be placed in a Sand-Heat, its Action will be rendered much ſtronger, and it will diſſolve much more of the Metal; and then if it be taken off, and ſet by to cool, it will, as it grows colder, have its attracting Power leſſened, and will let

let go a Part of the diſſolved Metal, which, as it precipitates, will be ſeen to form *thin cryſtal Flakes*, and fall in the *Form of Snow* to the Bottom; as will be very evident in ſuch a *Solution of Silver*.

32. In general if *Water*, *Salt*, or *ſome other Body* be put into a metalline Solution, it will be thereby weakened, and the metallic Parts, being attracted and united to thoſe of the Salt, *&c.* can be no longer ſuſpended, but will fall to the Bottom in form of a fine impalpable Powder; which, when the Fluid is poured off, and is dry, becomes a proper Subject for *ſilvering*. Fig. 6.

33. Thus ſuch a Powder obtained from a Solution of *Silver* is made uſe of by various Artificers for *ſilvering of Braſs*, *Copper*, &c. And thus a *Gold Powder* may be obtained by a Solution of that Metal in *Aqua Regia*, or *Aqua Fortis* in which *Salt* had been diſſolved. In order to perform this Operation with Succeſs, the Parts of the Metal to be ſilvered muſt be well cleanſed, and the Powder mixed with Salt of Tartar, and rubbed on with a Cork dipped in Water, after which it muſt be poliſhed and varniſhed. (See *Art.* 18.)

34. Theſe are ſome of the many Inſtances that might be produced to ſhew how intirely moſt of the Operations of CHEMISTRY depend on this Principle of Attraction, and can be accounted for moſt naturally by it. But many Proceſſes of *natural and artificial Chemiſtry*,

miſtry, are found to reſult from that other Part of this wonderful Power which acts by *Repulſion:* For as it was neceſſary that the Particles of Matter ſhould, in ſome Caſes, *attract and adhere to each other*; ſo, in other Caſes, it is as neceſſary they ſhould *repel and fly from each other*; that they may by this Means be qualified to produce all the different Kinds of *elaſtic Bodies*, and their various and ſurpriſing Effects in all the Scenes of Nature.

35. Thus the AIR is produced *by the Action of Heat* (proceeding from the *Particles of Light*) in all Bodies which ſeparate their Parts (on the Surface) *beyond each other's Sphere of Attraction*; and which then begin to repel each other, and ſo an imperceptible *Effluvium* of aerial Particles is generated from all Bodies, having a *centrifugal Force* between them, in which the *Springineſs* or *Elaſticity* of the Air does wholly conſiſt; but of this I ſhall ſay more in the *Pneumatic Lecture*, and illuſtrate this Operation by Experiment. Fig. 8.

36. Alſo by the Action of Heat (from the *Fire*, *Sun*, &c.) the Particles of Water being on the Surface ſeparated, immediately repel each other with a Force ſomewhat greater than that in Air; whence theſe aqueous Particles will have larger Interſtices, and muſt therefore be *leſs denſe than Air*, and ſo have a leſs *ſpecific Gravity:* Theſe aqueous

ous Particles therefore muſt riſe from humid Bodies into the Air in the Form of *Vapour*, till they arrive to that Part of the Air whoſe ſpecific Gravity is the ſame with their own; and there they will float about in thoſe large Collections we uſually call *Clouds*.

37. As the Gravity of the Air is greater or leſſer, the Clouds will be higher or lower; and when the Air ſuddenly becomes lighter, the *Clouds* or *Vapours* are precipitated; and in their haſty Deſcent are condenſed; and, coaleſcing into larger Portions, are render'd heavier than the Air, and of courſe fall thro' it in *Drops*, and thereby make *Showers of Rain*.

38. There is always a requiſite Degree of Heat in many Bodies to keep them in a fluid State; and the Cauſe of this Warmth or Heat (*viz.* the inteſtine Motion of the Parts, See *Art.* 30.) being ſubject to a Diminution by the Mixture of ſome Sorts of Matter, particularly Salt, it happens that when the *Nitrous Salts* (which have this Power in the greateſt Degree) are copiouſly mixed with theſe Vapours in the Air, they loſe their *Fluidity*, and become congealed into *Sleet*, *Snow*, *Hail*, &c. according to its leſſer or greater Proportion in the Mixture.

39. The Earth affords alſo a large Exhalation of *Sulphur*, which when it becomes mixed with the Nitre of the Air, and mineral Particles, which are copiouſly ſublimed from Mines and metallic Bodies, there will enſue a Fermentation, which when it is ſufficiently

ficiently excited, will produce *an Accenſion* or electrical *Flame*, and make what we call *Lightning*. In this Caſe the Spirit of the Nitre is greatly rarefied, and, if entangled and confin'd in the Body of the Cloud, expands itſelf with ſuch great Violence and Impetuoſity, as to make that *prodigious Exploſion* we call *Thunder*. All which is very evident by the common Experiment of *firing Gunpowder*, and by many Experiments in Electricity.

40. From hence alſo we ſee the Reaſon of thoſe chemical Proceſſes we call *Diſtillation*, *Sublimation*, &c. which are nothing more than a *Fluid or Solid Body*, having its Parts by the Action of Fire ſeparated beyond their Sphere of Attraction, and by that Means put into a *repelling State*, in which they riſe from the Subject in the From of a *Steam*, and are by the Recipient condenſed again into a *Liquor*, or collected into a Body of fine *impalpable Powder*, called *Flowers*, *Sublimate*, &c.

Fig. 9. 41. From what has been premiſed, we may eaſily deduce the Cauſe or Reaſon of all the various Degrees of *Hardneſs* and *Softneſs*, *Fixity* and *Fluidity* in natural Bodies. For ſince this Power is proportional to the Quantity of Matter, and acts in thoſe Particles only that are in contact, or nearly ſo, it follows that the greater the Number of Particles or Quantity of touching Surfaces is, the greater will be the Coheſion; and therefore thoſe Particles

ticles whoſe Surfaces are large and plane, and their Figure ſuch as will admit of the greateſt Congruity or Quantity of Contact, muſt neceſſarily *conſtitute the moſt hard and conſiſtent Bodies.*

42. But if the Figure of the Particles is very irregular, by which Means they touch, partly by their plain Surfaces and partly by their angular Points, or in ſome ſuch like Manner, then the Degree of Coheſion between them muſt be leſs, and they will be liable to be moved among themſelves, and will therefore *conſtitute the more ſoft and yielding Subſtances or Bodies.* Fig. 10.

43. Laſtly, If the conſtituent Particles be of a *ſpherical Figure, they will touch each other in ſingle Points only*; the Coheſion therefore between them will be the leaſt poſſible; and they will be put into Motion with the leaſt Force, and ſo *conſtitute the moſt voluble or fluid Body.* Fig. 11.

44. We now proceed to account for the *Nature, and eſtabliſh the Theory of Vegetation* in all Kinds of Plants; and here we find, by examining their Structure with proper Glaſſes, that the lignous Subſtance of Plants and Trees is nothing more than *a Congeries or Aſſemblage of an infinite Number of capillary Tubes, all connected or bound together by tranſverſe Ligaments or Bands.* Theſe are ſhewn in a Preparation as here repreſented in the Figure. Fig. 12.

45. If either the Root or Stem of a Plant be cut tranſverſely with a very ſharp Knife, the Orifices of theſe Veſſels, or *vegetable Tubes*, will appear innumerable over all the Surface; and if an extreme thin Slice be taken off, and held up againſt the Light, it will appear almoſt tranſparent, by reaſon of ſuch a Multiplicity of Holes or Pores, ſomewhat like what you ſee in the Figure.

Fig. 13.

46. The Veſſels or Tubes appear in the Solar Microſcope to be of two Sorts, *viz.* one, which are large, deſtined for the Paſſage or Circulation of *Air* thro' the Body of the Plant, and are therefore called *Air-Veſſels*; and theſe are they which appear ſo plainly and numerous to the naked Eye in thoſe Pieces of the *Convolvulus* (or *Bithwind*) which I ſhew in the Lecture.

47. For as to the *ſecond Sort*, they are ſo exceeding ſmall as not to be diſtinctly ſeen with the Eye alone, nor ſufficiently magnified by any other Inſtrument than the *Microſcope*. Theſe are fitted on this Account to attract the Moiſture or nutritious Juices of the Earth, by means of the Roots thro' which they are continued in innumerable and *minute Ramifications*.

48. That the larger Veſſels contain and circulate the Air is beyond Diſpute made evident by many curious Experiments on the Air-pump; and that the ſmaller Sort have an *attracting Power* (the ſame as

Fig. 14.

the afore-mentioned Capillary Tubes in Glaſs, *Art.* 21.). For by a new Experiment we ſhew that a *vegetable Siphon* AB attracts and draws the Water out of the Glaſs in the ſame Manner as the *Glaſs capillary Siphon* did (*Art.* 26.). And this affords an *ocular Demonſtration* of the Force there is in Plants to draw up their nutritious Juices from the Earth. And as the Height to which it muſt riſe in Trees is very great, it was neceſſary that the Veſſels ſhould be exceeding ſmall for that Purpoſe, as is evident from *Art.* 23.

49. That the *Sap* riſes by means of theſe Tubes, thro' all the Body of the Tree (and not between the Bark and the Wood as is uſually ſuppoſed) is evident from the following Experiment. AF is a Part of a Bough with the Bark taken off all round in two Places BC and DE, and from the intermediate Part CD there grows a Twig G, whoſe Leaves will grow and flouriſh all the Seaſon of Vegetation, as well to Appearance as any of the reſt on the Tree, as will alſo all the Leaves on the Twigs beyond the Part A. From whence it follows, that all the Nouriſhment of theſe Leaves muſt be derived from the Sap which is carried to them by the Tubes which go off from the Body of the Bough thro' the Stem of the Twig G, ſince the Wood where the Decortications are made is perfectly dry all the Time. Fig. 15.

50. Again it appears by this Experiment, that after the Tree is ſupplied by this means with Sap for *Vegetation*, and the Leaves have attained their *full Growth*, that Part of the Sap returns from the extreme Parts between the Bark and the Wood, becauſe we ſee the upper Parts of the Inciſions of the Bark at B and D become ſwollen, protuberant, and callous to a great Degree; whereas the lower Parts at C and E ſhrink in, and look dead; which plainly argues the Sap is obſtructed in its Return or Deſcent at B and D, and there lodging, ſwells out the Lips of the Inciſion, while none coming to the Parts C, E, they become emaciated and withered.

51. Again, this *returning Sap* ſeems neceſſary for the Support of the Leaves after they have arrived to their full Growth, for tho' the Leaves on the Twig G vegetate and grow equally with the reſt, yet they decline, ſicken, grow pallid, and die away ſome time before the reſt on the other Parts of the ſame Bough and Tree. And even thoſe on the Bough, beyond the Decortication B C, will not continue their Verdure and healthful State ſo long as the other Leaves of the Tree.

52. But to put this Matter beyond all Doubt, I tried the following Experiment. I ſeparated with a Knife the two Twigs C and E from the Body of a Bough A G, and kept them ſo by a ſmall Wedge

Fig. 16.

Wedge under each; then at B, juſt above and over the Part D, I cut away the Bark to prevent any Sap from returning to the Twig C from above, and as none could come to it from the Body of the Bough, being ſeparated from it, the Conſequence was, that the Twig and its Leaves immediately died and withered away; whereas thoſe on the Twig E, being ſupplied with the deſcending Sap, continued their Verdure equally with the reſt on the Tree till the Fall.

53. Theſe vegetable Ducts or Tubes we have been ſpeaking of, and of which the lignous Part of the Plant is made, are detached from the Boughs in ſmall Portions thro' the Foot-Stalk or Tail of the Leaf, under proper Integuments, to be diſtributed thro' all the Body of the Leaf, where they perſpire or throw off all the ſuperfluous Part of the Sap. Theſe *tubular Fibres*, as they are contained in the Tail of the Leaf, prepared, diſſolved, and expanded, you ſee repreſented in *Fig.* 17.

54. The beautiful and wond'rouſly fine Ramifications of theſe Veſſels thro' the Leaf itſelf you ſee in *Fig.* 18 and 19, where you obſerve moreover that each Leaf is a Duplicature of theſe Veſſels, or conſiſts of *two Syſtems or Layers of Fibres*, one of which is very fine, as *Fig.* 18, and the other much coarſer, *Fig.* 19. Theſe anſwer to the *Syſtem* of Arteries and Veins in an

Fig. 18. Fig. 19.

animal Body. And into theſe two Parts, many Leaves (as thoſe of *Holly*, *Apple-trees*, *&c.*) do naturally reſolve themſelves in their Preparation in Water, of which the two preſent Figures are an Inſtance.

55. I ſhall only further obſerve, that this extreme Ramification of the Veſſels in a Plant is every Way analogous, or alike to that in animal *Arteries and Veins*, as I ſhew by a Specimen of theſe *latter injected*, compared with the *Leaves anatomized*. There is alſo a further Similitude *in the Contexture of theſe organized Bodies*, which I alſo illuſtrate by *proper Specimens and Preparations in each*.

56. Indeed there is this Difference in the Oeconomy of Nature in animal and vegetable Bodies; that in the former ſhe makes uſe of the *muſcular Force of the Heart for the Pulſion, Protruſion, and Circulation of the Fluids and Juices* by which the Body is nouriſhed; whereas this in the latter is effected *principally by the capillary Attraction*, in the Manner as above explained.

57. In the laſt Place with reſpect to Plants I ſhew *by Preparations of Bark and Wood*, that the Plant or Tree does each Year increaſe by the *Addition of a lignous cylindric Shell*, which firmly adheres to the former, and which is yearly derived from the *interior Bark*, which contains them in almoſt infinitely thin *Laminæ*; one of which from Year to Year has its Veſſels expanded by the

Sap,

Sap, and grows by Degrees into a thick woody Subſtance, conſiſting of *Sap and Air-veſſels*; and by a Kind of *vegetable Articulation* it is naturally fitted into, and unites with the Wood of the preceding Year.

58. Having thus ſufficiently illuſtrated the Nature and Uſe of this *univerſal Power of Attraction and Repulſion*, I ſhall in the next Place juſt give an Inſtance of the Nature and Uſe of another Power of *Attraction and Repulſion*, which is *of as ſingular a Kind*, as it is formed to affect only two Sorts of Matter, *viz.* the *Load-ſtone* and *Iron*; but it poſſeſſes the former in a moſt eminent Degree.

59. This Virtue is emitted from two Parts of the Stone or Magnet in a very fine imperceptible Effluvium; and if Pieces of Iron be properly placed over thoſe two Parts, it will be as it were attracted, accumulated and condenſed in the Iron, and from thence will be emitted or communicated with much greater Force and Intenſity than from the Stone itſelf.

60. The Criterions or Marks of a good Magnet are *Blackneſs*, *Hardneſs*, and *Heavineſs*. It attracts and repels Iron, but touches no other Sort of Matter; the ſame End of a ſuſpended Needle which is attracted by one End of the Stone, is repelled by the other. It may be communicated from the Stone to Iron, which if formed into a Needle, and ſuſpended on a fine Point, will turn into

a Poſition towards the *North and South*, and there it will ſtand at Reſt.

61. The Angle ACN, which the magnetic Needle A B makes with the meridian Line N S, is called the *Variation of the Needle*; and this being the ſame in any one Place for a long time, or known by Obſervation for any particular Place and Time, renders it of the greateſt Service in Navigation: Becauſe it gives you the Angle ACF which the Ship's Courſe D F makes with the Needle A B; and therefore the Angle NCF, which it makes with the Meridian N S; whence, by allowing for Lee-way, the Mariners are able with great Certainty and Exactneſs to compute every Thing relating to the *Departure*, *Difference of Longitude*, *Difference of Latitude*, *Diſtance ſailed*, &c.

62. The magnetic Needle is alſo very uſeful in conducting Travellers thro' unknown Countries and Roads by Land, by preſenting to their Views at all Times the Bearing or Point of the Compaſs on which the Place they are going to lies. It is likewiſe very uſeful to ſhew the Hour of the Day whenever the Sun ſhines, in thoſe called *Compaſs Dials*. Alſo by knowing the Hour of the Day, you find the true Declination of the Needle for any Place. All which, and many other Particulars, are illuſtrated and exemplified in the Lecture, by *Magnets both natural and artificial*.

63. If

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Plate I.

Fig:1.

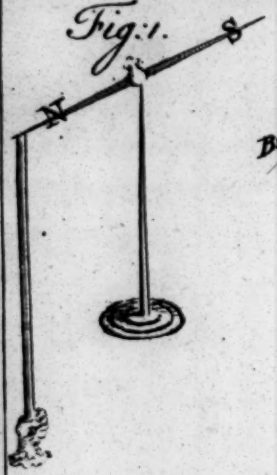
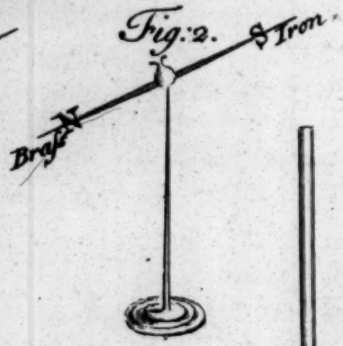


Fig:2.



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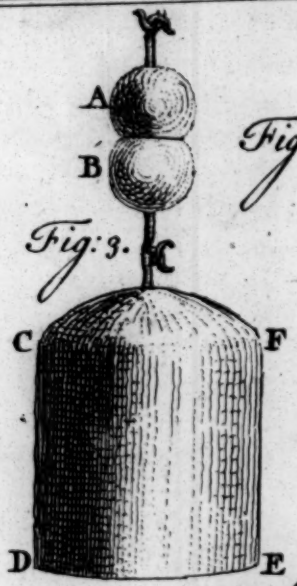
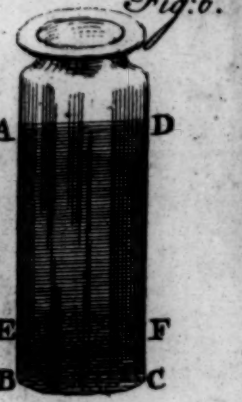


Fig:4.

Fig:5.

Fig:6.



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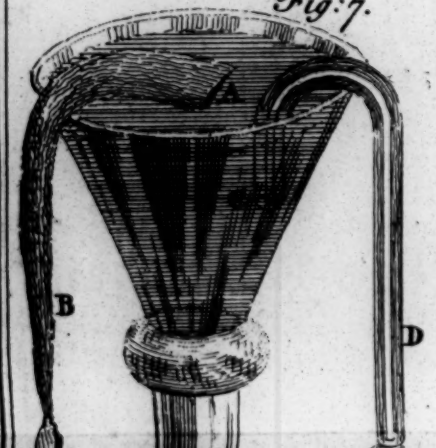


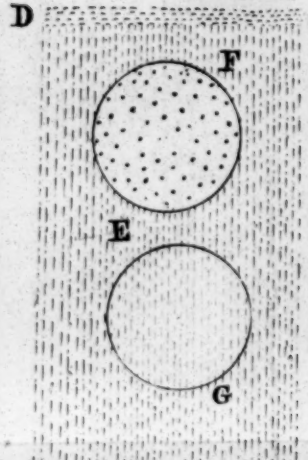


Fig:9.

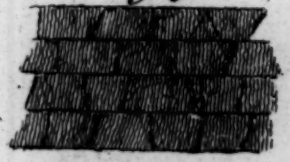


Fig:10.

Fig:12.

Fig:13.

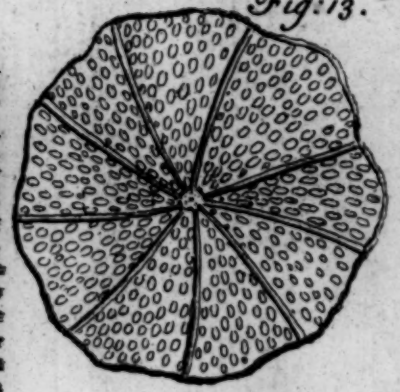


Fig:14

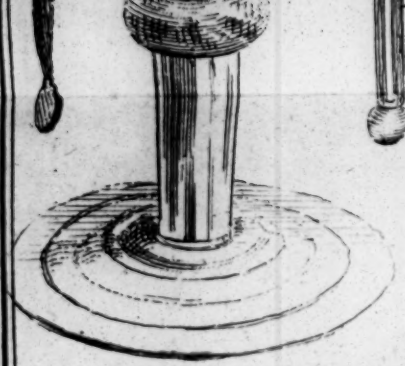


Fig:8.

Fig:11.

Fig:17.

Fig:14

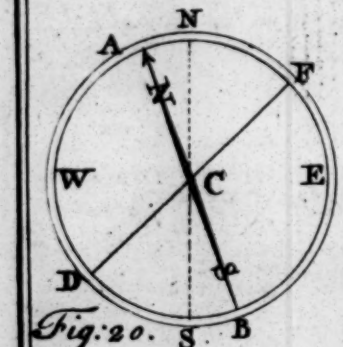
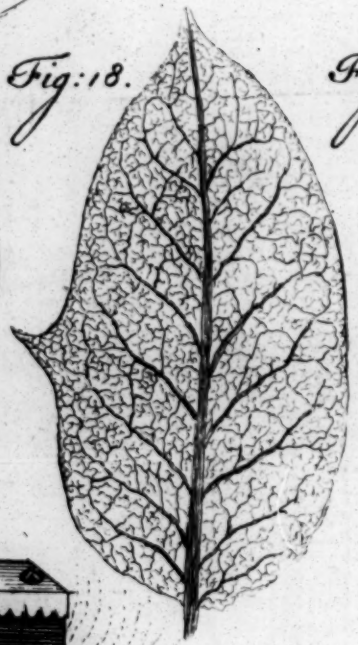


Fig:20.

Fig:18.



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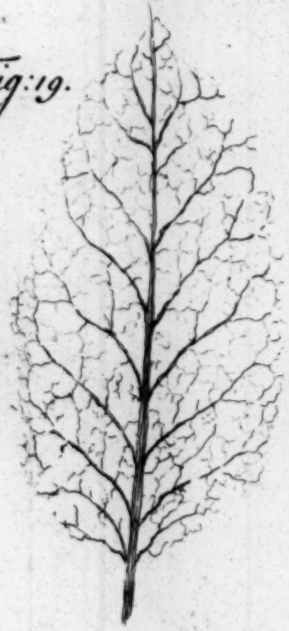


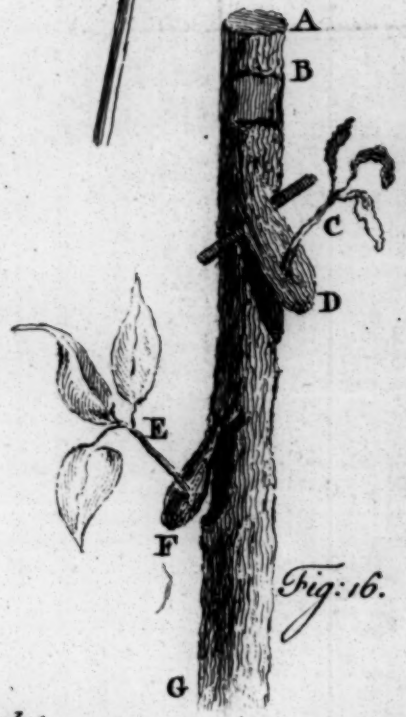
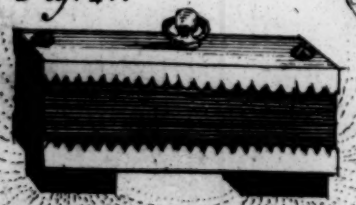


Fig:16.

Fig:15.

Fig:21.



E. Bowen sculp:

63. If a few Steel-filings be ſifted finely over a Sheet of fine Paper, and the Magnet placed in the Midſt of them, it will be very pleaſant to obſerve how all the Steel Particles are affected with the Virtue iſſuing from each Pole of the Stone, by which they are moved into Curve-lined Directions, and circular Poſitions between the Poles, very much like what you ſee repreſented in *Fig.* 21. From whence we learn that there is a Kind of Circulation of this Virtue from one Pole or Part of the Stone to another. Dr. *Halley* ſuppoſes, with a great deal of Reaſon, that there is a large central Magnet in the Body of the Earth, and that it is moveable in the Earth like the Kernel of a Nut in the Shell, which by that means cauſes all the *Variety of the Declination* of the Needle, and alſo its *dipping below the Horizon of a Place*. He alſo ſuppoſes the external Shell of the Earth to be magnetical; and which, not having a ſimilar Motion and Poſition with the *Nucleus* or internal Magnet, occaſions all the Irregularity in the Variations of Motion of the Needle.

Fig. 21.

Fig. 4.

SECTION

SECTION II.

The Nature of LIGHT *explained, the Laws of* REFLECTION *and* REFRACTION *of* LIGHT, *the* Nature *and* Effects *of* MIRROURS *and* LENSES, *the* Priſmatic COLOURS *of* Light, *the Nature of* VISION *by a* Natural *and* Artificial EYE, *of the Common* MICROSCOPE, *the Solar* MICROSCOPE, *of* Refracting *and* Reflecting TELESCOPES, *of* Camera Experiments *and* Inſtruments.

1. THE Subject of this Section is the Doctrine of *Light, Colours, Viſion,* and *optical Inſtruments.*

2. LIGHT conſiſts of the moſt ſubtle or ſmalleſt Parts of Matter, and is appointed by Nature the *material Cauſe* of *Viſion* or *Sight.* Its *luminous Quality* depends upon the Minuteneſs of the Parts, and the great Velocity of their Motion. For as the Particles of Light are the ſmalleſt of all others, ſo they move with the greateſt Swiftneſs; for by Experiment it hath been found that it

it moves at the Rate of *Ten Millions of Miles in a Minute.*

3. This Kind of lucific Matter was at firſt all collected into a Body of an enormous Size, to ſerve as a Magazine or general Receptacle of Light; this we call the SUN, from which the Light is conſtantly diſpenſed thro' every Part of the Syſtem, to anſwer all the Purpoſes of *Light, Viſion, natural Heat, Vegetation,* &c. in the ſeveral planetary Worlds.

4. Theſe Particles of Light emitted from the Sun, and falling upon the Surface of Bodies, are in Part reflected from the Surface, and in Part imbibed into or refracted thro' the Subſtance of the Body. Thus let Plate II. A B be the Surface of a plain Mirrour, Fig. 1. D C the Ray of Light falling thereon at C, and let C E be perpendicular to the ſaid Surface; *then will the Ray* D C *be ſo reflected into the Ray* C F, *as to make the Angle of Incidence* D C E *equal to the Angle of Reflection* E C F, as is very evident by Experiment in the *Camera Obſcura.*

5. That Part of the Beam which enters the Subſtance of Bodies, puts their Parts into Motion, and according as it is imbibed and detained in a greater or leſſer Degree, it actuates the Parts of thoſe Bodies more or leſs, and produces in them ſuch Degrees of Motion, which, when it affects our *nervous Syſtem,* excites in our Minds the *Ideas of Warmth, Heat,* &c. by thoſe of *Feeling*; and

and of *Light, Flame, Colours,* &c. by thoſe *appointed for Viſion.*

6. When the Parts of Bodies and alſo their Pores are ſo large as to cauſe ſuch irregular Reflections and Refractions of the Light thro' the Subſtance, that it cannot go on, or be tranſmitted thro' it in right-lined Directions, it is evident we can ſee none of the internal Parts of that Body, which is therefore ſaid to be *opake*. As on the other Hand, that Body is *tranſparent*, which tranſmits the Light ſo regularly thro' its Subſtance to the Eye, that all its internal Parts are thereby rendered viſible.

7. In theſe Sorts of Bodies we determine *the Law of Refraction* by Experiments in many different Ways; one of which, as it is very eaſy, I ſhall here explain. Let ABCD be a Veſſel, ſet in the dark Room, where the Beam of the Sum E F ſhall juſt touch the Top of the Side A D, and paſs on to the Point F at the Bottom. Then filling the Veſſel with *Water* to the Brim, the Ray of Light E A will not now go thro' the *Water* to F as before, but will be bent into the Direction A G, which is therefore called the *refracted Ray*, and the Angle D A G is the *Angle of Refraction*; as D A F is that of *Incidence*.

Fig. 2.

7. If on the Side A D we deſcribe with the Radius A D the Arch of a Circle D M, and from the Points H and K, where it interſects

ſects the refracted and incident Rays, the Lines H I, K L be drawn perpendicular to A D, theſe are called the Sines of the Angles D A G and D A F; and are always to each other in the Proportion of 3 to 4 nearly in *Water*; as 2 to 3 in *Glaſs*; and as 2 to 5 in *Diamond*. Whence it appears, that the greater the *Denſity* of the refracting Medium, the greater will be its *refractive Power*, tho' not exactly in the ſame Proportion; but here we muſt except *Oils and ſpirituous Liquors*.

9. We ſhall now apply the Doctrine of *reflected Light* to account for the Effect of *concave and convex Mirrours*. Let A B be a Segment of a hollow Globe of Glaſs, whoſe Center is C, and Quickſilvered on the convex Part A B. The Ray or Right-line H V, that paſſes thro' the Center C, and falls on the middle Point or *Vertex* V of the Mirrour, is called the *Axis* of the Mirrour; let D G be another Ray from the Sun parallel thereto, and thro' the Point of Incidence G draw C E, this will be perpendicular to the Mirrour in G, then make the Angle C G F equal to the Angle C G D, and G F will be the *reflected Ray*; and the Point F will be in the Middle between C and V, and is called the *Solar Focus*, becauſe all the Sun's Rays will be there collected into a ſmall bright Spot, and burn very intenſely; all this is evident from the Law of Reflection in *Art.* 4. Fig. 3.

10. Sup-

10. Suppose any *radiant or luminous Body* were placed near the Mirrour in the Axis at (*d*), and let *d* G be a Ray of Light passing from it to the Mirrour in G; then make the Angle C G *f* equal to the Angle C G *d*, and G *f* will be the reflected Ray, and the Point *f* will be nearer the Center C than the Point F. If the Point *d* coincides with the Point C, then the Ray will be reflected upon itself. If the Radiant be at *f*, and *f* G the incident Ray, then G *d* will be the reflected Ray. If the Radiant be placed in the Focus F, the Ray F G will be reflected into G D parallel to the Axis. And lastly, if it be placed nearer the Mirrour as at K, the reflected Ray K G will be G I, proceeding from the Mirrour as if it came from the Point M in the Axis of the Mirrour behind it. All this is evident likewise from the same Principle in *Art.* 4.

11. Hence we may easily infer every thing relating to the *Formation of the Images of Objects* in a concave Mirrour; for let A B be such a Mirrour, and O B an Object placed beyond its Center C, then since the Axis C V is perpendicular thereto in the Vertex V, the Particle of Light coming from the Point O, of the Object in the Direction of the Axis, will be reflected back in the same Direction to its Focus at I, where that Point O will be represented. Then from the other extreme Point B let a Ray proceed

Fig. 4.

to

to V, and making the Angle I V M equal to B V O, we have V M the reflected Ray, and the Point M will be the Repreſentation of the Point B. And hence all the Rays proceeding from every Part between O and B will be reflected to the Line I M, and ſo the whole Line I M will be the Repreſentation or Image of the Object O B.

12. Hence it appears that the *Poſition of the Image*, with reſpect to that of the Object, muſt neceſſarily be *inverted*, and on the contrary Side of the Axis. Hence alſo it appears, ſince the Object and Image are both ſeen from the Vertex of the Mirrour under equal Angles B V O, and I V M, *the Length of the Object will be to that of the Image as the Diſtance of the Object* O V *to the Diſtance of the Image* I V *from the Mirrour*.

13. Therefore, while the Object is farther from the Glaſs than the Center C, the Image will be on *the ſame Side*, but *nearer to it*, and *leſs than the Object*. If the Object were placed in the Center C, the Image would be there formed alſo, in an inverted Poſition and *equal* to the Object: If the Object be placed between the Center C and Focus F, as at I M, then will O B be the Image formed beyond the Center, *inverted* and *magnified*. If the Object be placed in the Focus F, the Rays will be all reflected parallel to the Axis, and form the Image at an *infinite Diſtance*, and infinitely large. Laſtly,

ſuppoſe

ſuppoſe the Object placed any where between the Focus F and the Vertex V, as at K,

Fig. 3. the Image will be formed behind the Glaſs at M, in the *ſame Poſition* as the Object, and *magnified*. Theſe are the *principal Properties of concave Mirrours*, which are all of them demonſtrated by Experiments.

14. In the ſame Manner I might ſhew, that Rays of Light falling on a *convex Mirrour*, and reflected by the ſame Law (*Art.* 4.) will all proceed diverging from the Glaſs in ſuch Manner as if they came from a Point behind it; ſo that theſe Glaſſes have no real *Focus* or burning Point, they form the Image *only behind, always erect*, and *leſs than the Object*, ſo that no magnifying Power belongs to this Glaſs, when uſed ſingly by itſelf. Theſe Things appear alſo by Experiments with thoſe Glaſſes.

15. If the Rays of Light paſs thro' a Glaſs whoſe Surfaces are plain, they cannot be re-

Fig. 4. fracted towards one Point or Focus; but if one or both the Surfaces are convex, they will be ſo refracted as may be thus eaſily ſhewn: Let A B D be ſuch a *convex Glaſs* or *Lens*, C K its Axis, and let the convex Surface A B be deſcribed with the Radius M E, and the Surface A D with the Radius C O, and let F E, a Ray of Light parallel to the Axis, fall on the Lens at E, which as it there meets with the *denſe Medium* of Glaſs will be refracted out of its parallel Direction

E N

E N into another E K, ſo as to make the Sine of the Angle of Incidence M E N, to the Sine of the Angle of Refraction K E N, as 3 to 2 (as is evident from *Art.* 7, and 8.) The Ray F E therefore will by the firſt Refraction tend to a Point K in the Axis.

16. But as the Ray, paſſing thro' the Glaſs from E to O, there meets with another *convex Surface*, where it muſt now be refracted into a *rarer Medium*, or Body of *Air*, therefore the Ray E K will now be refracted into another O L, ſo as to make the Sine of the Angle of Incidence P O K to that of the Angle of Refraction P O L as 2 to 3. The Ray F E, therefore, after Refraction at both Surfaces, will meet the Axis at the Point L.

17. If the two Surfaces A B, A D, be equally convex, or the Radius C O be equal to M E, then will the Point L coincide with M; or *parallel Rays*, by means of ſuch a Glaſs, will be converged to a *Focus*, at the Diſtance of the *Radius of Convexity*. Thus the parallel Rays A B C D falling on a *double* and *equally convex Lens* will be all converged to the Focus F, where they all croſs each other; and from thence go diverging towards G and H. Fig. 6.

18. Let A H be the Axis of a Lens D E; then if O be any luminous Point in the ſaid Axis, the Rays which proceed from it to the Lens D E will all be re- Fig. 7.

Fig. 7. fracted or converged to a Focus in the Point I on the other Side. And if O B be an Object, then all the Rays proceeding from the other Extremity B to the Lens will be refracted to the Point M in the right Line B M, paſſing thro' the Center of the Lens C. Therefore all the Rays from every Point between O and B in the Object will be collected reſpectively into ſo many Points between I and M, and thereby conſtitute an Image I M of the Object O B, in an *inverted Poſition*.

19. Becauſe only parallel Rays can be converged ſo near the Lens as its Focus F (by *Art.* 17.) therefore Objects only at an *infinite* or a *very great Diſtance can have their Images formed in or very near the Focus of ſuch a Lens*. If the Object O B approach towards the Lens, the Image I M will recede from it, and become bigger and bigger, till the Object arrives to the Point which is double the focal Diſtance from the Lens, *and there the Image will be alſo at the ſame Diſtance on the other Side*, and equal to the Object. As the Object O B proceeds from hence towards the Lens, the Image I M will recede farther, and become bigger than the Object; till the Object arrives at the Focus of the Lens, and then the Image, being formed by *parallel Rays*, muſt be at an infinite Diſtance and infinitely large. Laſtly, if the Object be nearer the Lens than the Focus, *the Image will become negative, or formed on the ſame Side*

Side with the Object, and always bigger than the Object, and in an *erect Position*.

20. Theſe are Properties of a *convex Lens*. As for *concave ones*, they are quite the reverſe; thus if the *parallel Rays* A B C D fall on a concave Lens, they will be refracted into a *diverging State* toward G and H, in ſuch Manner as if they came from a *Focus* F on the other Side. If the Lens be a *Plano-concave*, this Point F, or *virtual Focus*, will be at the *Diſtance of the whole Diameter of the Sphere of Concavity*. If it be double and equally Concave, the Point F will be *in the Center of Concavity*. Fig. 8.

21. If *converging Rays* G H tend to a Point F, and a *Concave* Lens B C be ſo placed to intercept them, that its virtual Focus ſhall coincide with the Point F, then will thoſe Rays after Refraction go *parallel to the Axis of the Lens*, as repreſented in the Figure.

22. Having thus accounted for the Nature and Laws of Refraction, it will now be eaſy to account for the *Colours of Bodies* by Experiments of the *Priſm*. For let A B be a Priſm, and C D a Beam of Light falling upon it in the Point D; it will paſs thro' and be refracted on the other Side at E, in ſuch Manner, that the refracted Ray R E ſhall make an Angle with the Perpendicular E F greater than the Angle H E F, which the Incident Ray C H makes with it, by the Law of Refraction (*Art.* 7.) Fig. 9.

23. But then we ſhall obſerve that the Rays of this Beam will not be equally refracted, but ſome Part will go to R, another Part will be more refracted, and go to O; another Part to Y; another to G; other Parts to B and I; and that which is moſt of all refracted, to V.

24. Now ſince the *refracting Power of the Priſm is* every-where the ſame, if the Rays or Particles of Light were all of the ſame Size or Magnitude, they muſt neceſſarily be all equally or alike refracted, *viz.* to one and the ſame Place. But as this is not the Caſe, it evidently follows, that theſe luminous Particles are of *various different Magnitudes*; and that thoſe which are largeſt, and, of courſe, leaſt ſubject to the refracting Power, will *be leaſt of all refracted*, and therefore fall neareſt the Perpendicular, *viz.* in the Direction E R. As on the other Hand thoſe which are of the *leaſt Size muſt needs be moſt refracted*, and will go from E to V; and all the intermediate Rays, according to their ſeveral Magnitudes, will fall between R and V.

25. And here we are next to obſerve, that as *Nature has cauſed the Idea of Viſion in general to ariſe from the Action of a Particle of Light upon the optic Nerve in the Eye*, ſo this Idea of the *Form* is always connected with another which we call COLOUR, and which ariſes from the peculiar and different Action

or

or Force with which each particular Ray affects the Nerve. Thus the Rays E R being largeſt, ſtrike with the greateſt Force, and by that excite the Idea of *Redneſs* in the Object which emits it. Again, thoſe which are leaſt of all, and ſtrike the Nerve with the leaſt Force as the Rays E V, make the Idea of a *Violet Colour*; and the Rays at O make an *Orange Colour*; at Y a *Yellow*; at G a *Green*; at B a *Blue*; at I an *Indigo*, and at V a *Violet Colour*. All which Particulars appear extremely plain and beautifully by the Priſm in a dark Room.

26. Hence, ſince we find by common Experience, that there is in different Parts of Matter a *different Power of Attraction and Repulſion* (Sect. I. Art. 2.) that is, in this Caſe, of *Refraction and Reflexion of Light*, it muſt follow, that thoſe Bodies *whoſe Particles have a Power of reflecting or refracting any one Sort of Rays alone, or more copiouſly than the reſt*, muſt neceſſarily appear of that particular Colour which is cauſed by thoſe Rays. Thus *Vermilion* throws up all the *red-making Rays*, and imbibes the reſt, and muſt therefore appear *red*. Gold reflects all the *yellow-making Rays*, and ſo muſt appear *Yellow*; and the ſame may be ſaid of all the reſt.

27. If, as in ſome Caſes it happens, a Body reflects one Sort of Rays, and tranſmits another, it muſt neceſſarily appear *of one Colour by Reflection, and of another by Re-*

fraction. Thus Leaf-gold appears *Yellow* by *reflected Light*, but of a fine *Azure* or *Blue-green* by refracted Light. Alſo a Tincture of *Lignum Nephriticum* appears of a deep *Blue by reflected Light*, but *Red by the Light refracted thro' it.* All which is confirmed by Experiment.

28. The Rays of Light are not only *ſeparated by Refraction*, but alſo *by Reflection*; and hence in ſome Kinds of Bodies where the Power of Reflection is uniform, the Rays of Light muſt, according to their ſeveral Magnitudes, be reflected under different Angles; whence the Eye placed in one Poſition ſees the Object of one Colour; in another Poſition, of another Colour; and thus by moving the Eye or Object, the ſame Part ſhall appear of different Colours ſucceſſively, as is evidently ſhewn in a *Peacock*'s *Feather*, the *Wings* of *ſmall Flies*, *thin Bubbles* of *Soap Water*, *Silks*, *Satins*, &c.

29. Thoſe Bodies which reflect all the Rays of Light as they fall, muſt neceſſarily appear of the ſame Colour with the Sun's Light, *viz. white*; and ſuch Bodies as imbibe or abſorb almoſt all the Rays of Light, muſt appear *dark* or *black*, *i. e.* without any Colour at all. Hence the Reaſon why *white Bodies are of a ſtronger and more laſting Texture than black ones*, whoſe Parts being always ſubject to the Action of a much greater Quantity of Light, are ſooner brought to a State

State of Separation or Diſſolution, *i. e.* of *Rottenneſs.*

30. Thus much for the *Rationale of Colours*; we ſhall next ſhew how VISION is *cauſed by the* EYE; in order to which we muſt firſt conſider its *Form*, *Structure*, and other Circumſtances conducive to this great Effect. And firſt, ſince the Nerves are appointed the *general Organs of all animal Senſation*, the Eye being placed in the Head, a Portion of Nerves is ſent from the Brain to each Eye, in a round Bundle, as N M; where it enters the Eye at M, and from thence is expanded into a fine Membrane or Lining over all the interior Part of the Eye as far as S and T: This Expanſion of the optic Nerves is called the *Retina*, and is the *immediate Organ of Sight.* Fig. 10.

31. For upon this the Rays of Light coming from every Point in an Object O B are convened by the *convex Figure* of the fore Part of the Eye K P L, and thereby an Image I M is formed in the Focus; which in an Eye well formed is nicely at the Bottom on the *Retina.* For this Purpoſe it was neceſſary the convex Part ſhould be tranſparent, to admit the Rays of Light freely; and it is called the *Cornea*, or *horny Coat* of the Eye, from its likeneſs to *Horn* when dried.

32. In order to keep this Cornea of a due Degree of Convexity, Nature has appointed a clear Fluid, limpid and tranſparent as *Water*, and is therefore called the *aqueous* or

watry Humour; this fills out the *Cornea*; and in caſe it is loſt by a Wound or Puncture in the *Cornea*, it is ſupplied again.

33. The next Part we meet with, is a Sort of Diaphragm or Membrane, called the *Uvea*, with a Perforation or Hole in the Middle at O O, called the *Pupil:* The Pupil is deſigned to adjuſt the Quantity of Light for *diſtinct Viſion*. For this Purpoſe, the Uvea conſiſts of two Orders of *muſcular Fibres*, one of a circular Form on the Outſide, and by theſe the *Pupil is contracted for the Excluſion of ſuperfluous Rays, when the Object is too luminous and bright*. And by another Set of Fibres on the Inſide, diſpoſed in a different Manner, like Rays from a Center, the *Pupil is dilated to receive more Rays, when the Object is remote and dark*.

34. Behind the Uvea we meet with a moſt curious Part S T, called, from its Clearneſs and Conſiſtence, the *cryſtalline Humour*; it is like a ſmall thick Glaſs Lens, more convex behind than before. It is connected to the Coats of the Eye all around on the Inſide by a Set of *muſcular Fibres*, proceeding from the *Ligamentum Ciliare*, and is thereby ſuſpended juſt behind the Pupil; it is included in a very fine Tunic called the *Arachnoides*: This Part is deſtined for correcting the firſt Refraction at the Cornea, and adjuſting and perfecting the Image upon the *Retina*; which is done by occaſionally altering its Diſtance from

from the Retina, and the Convexity of its Surfaces, by the above-mentioned Ligament.

35. The third and largeſt Humour of the Eye is called the *glaſſy Humour*; it makes the Globe or Body of the Eye, and is every Way very much like the *White of an Egg*: It is repreſented by the Space S I M T in the Figure of the Eye, and is very tranſparent. The Uſe of it is to give free Admiſſion to Rays of Light to the *Retina*, which everywhere encompaſſes it, and to keep the Eye of a *globous Figure*. The Bottom of the Eye is not of a *plane*, nor yet of a *ſpherical Figure*; neither of which would admit of a true or perfect Formation of the Image on the *Retina*.

36. By this wonderful Structure and Mechaniſm of the Eye, the Image I M of any Object O B is formed on the *Retina*, exactly in the Manner as by a Glaſs Lens, as ſhewn before from *Art.* 15 to 20. And tho' the Image be *inverted*, yet we muſt neceſſarily ſee the Object *erect*, becauſe the *Idea of Poſition* depends upon the *Direction of the Ray of Light*; and as theſe Rays croſs each other in the Pupil, it follows, that the Particle of Light at I muſt excite the Idea of Viſion at the Point B in the Object, it being referred thereto by the right-lined Direction of the Ray I B; and thus the Point M is referred to O, and ſo of all the reſt; whence the Object muſt neceſſarily appear erect.

37. The

37. The Nerve N M is not inſerted in the Middle of the Bottom of the Eye, but on the Side; for this Reaſon, that all the Rays of Light that fall on the Part where the Nerve enters the Eye are loſt, and had it been inſerted at Q, juſt oppoſite to the Pupil, then all the Rays which enter the Eye directly, and make the moſt perfect Part of the Image I M had been loſt, and we ſhould have ſeen a Hole or black Spot in the Middle of all Objects, as we eaſily ſhew by Experiment.

38. When the *Cornea* K P L is too convex, the Rays of Light are converged to a Focus, before they arrive to the *Retina*, and therefore the Image upon the *Retina* muſt in that Caſe be very indiſtinct and confuſed. Such an Eye is called a *Myops*, and makes *People ſhort-ſighted*, that is, it obliges them to hold what they ſee at a ſhort Diſtance from their Eyes, in order to prolong the focal Diſtance, and make it reach the *Retina* to imprint the Image perfectly thereon. And for remote Objects they uſe a concave Glaſs, which produces the ſame Effect, by cauſing the Rays to go leſs converging to the *Retina*.

39. When the *Cornea* is too flat, as generally happens by Age, the Rays tend to a Focus beyond the *Retina*; and this alſo cauſes the Image to be very imperfect and indiſtinct upon it; ſuch People are therefore called *Preſbytæ*; and their Remedy is a *Pair of Viſuals* with *convex Glaſſes*, or Pebbles, which make the

the Rays converge ſooner, and imprint the Image duly on the *Retina*. Every thing hitherto advanced in regard to Viſion, and the Defects thereof, together with their Remedies by Glaſſes, are ſhewn by the *Diſſection of the natural Eye*, and *Experiments with an artificial Eye*, repreſenting every Part, and the Effects of the natural Eye completely.

40. It now remains that we ſhew the Nature, Uſe, and Effects of the moſt conſiderable *optical Inſtruments*; the principal of which are the MICROSCOPE and the TELESCOPE. The firſt of theſe are ſo called from their repreſenting Objects plainly to the View, which, by reaſon of their *Smallneſs*, cannot be diſtinctly ſeen with the naked Eye. And *Teleſcopes* have their Name from their perfecting, at leaſt improving, our Viſion of diſtant Objects, which appear under an Angle too ſmall to be diſtinguiſhed by the Eye alone.

41. Of MICROSCOPES there are three Sorts in Uſe, *viz.* The *ſingle*, the *double*, and the *ſolar Microſcope*. The Nature of the two firſt depends on theſe following Conſiderations, *viz.* (1) That we cannot diſtinctly ſee any Object at a *leſs Diſtance than 6 or 7 Inches from the Eye*. (2) That the nearer any Object is, the larger is the Angle under which it is ſeen, and the Dimenſions under which it appears. (3) That *parallel Rays*, or ſuch as are nearly ſo, can only have their Focus at the

the Bottom of the Eye. And (4) that any Object placed in the *Focus* of a *convex Lens* will have the Rays proceeding from it all refracted by the Lens parallel to each other (See *Fig.* 6.).

42. Thus ſuppoſe A B a ſmall Object placed in the Focus of the little Lens DE, and then all the Rays which proceed from any Point C in that Object will, by the Lens, be thrown parallel upon the Eye F, which therefore will produce diſtinct Viſion of that Point; and ſince the ſame is to be obſerved of every other Point, it is evident the whole Object will be diſtinctly ſeen by means of the Glaſs.

Fig. 11.

43. Suppoſe the *focal Diſtance* C D to be *one Inch*, then will the Object be ſeen by the Glaſs *ſix Times nearer* than it can be without it (*Art.* 41.) therefore it will appear 6 Times *longer* and *wider*; and 6 Times 6, or 36 Times larger in *Surface*; and 6 Times 36, or 216 Times larger in *Bulk* or *Solidity* than it can appear to the naked Eye. But if C D be but $\frac{1}{10}$ of an Inch, the Object will be ſeen diſtinctly thro' the Lens 60 Times nearer than by the Eye alone; and therefore 60 Times *larger* and *wider*; 60 Times 60, or 3600 Times larger in *Surface*, and 216000 Times larger in *Bulk*; which tho' it be a prodigious Power of magnifying, yet theſe Glaſſes are common, and we have many of a much ſhorter focal Diſtance.

44. As

44. As to the DOUBLE or COMPOUND MICROSCOPE, they conſiſt of *two* at leaſt, but moſtly of *three Lenſes*; the firſt or ſmalleſt C is placed near the ſmall Object A B, *viz.* at a little more than its *focal Diſtance*; then will a large Image I H be formed of the ſaid Object, ſo much larger than the Object, as the Diſtance C I is greater than the Diſtance A C; and this Diſtance and Image may be made greater or leſs by placing the Object nearer to or farther from the Lens C. All which is evident from *Art.* 17, 18, 19.

45. Now this Image may be very diſtinctly viewed by any proper Lens, placed at its *focal Diſtance* from it, which Lens is called the *Eye-Glaſs*; and to know how much the Object appears magnified by theſe two Lenſes, ſuppoſe the Diſtance of the Image C I to be 6 Times the Diſtance of the Object C A, then will the Length I H be 6 Times the Length A B to the naked Eye; but this Length of the Image I H, if viewed by an *Eye-glaſs* of an Inch focal Diſtance, will appear 6 Times as large as it does to the bare Eye (*Art.* 41. 43.) Therefore the Image, thus viewed, will appear 6 Times 6, or 36 Times *longer* than the Object A B; 36 Times 36, or 1296 Times larger in *Surface*; and in Solidity 36 Times 1296, or 15552 Times larger than the Object. Fig. 12.

46.

46. But tho' the magnifying Power of this Microſcope be very conſiderable, yet the Extent or Field of View is very ſmall and confined; and therefore in order to inlarge it, and thereby render it more delightful, another large Lens D E is placed below, by which the Angle D C E or A C B, under which the viſible Part of the Object lies, may be conſiderably inlarged, and the Image formed afreſh at F G; which Image F G now lies within the two extreme parallel Rays of the *Eye-glaſs* M F and N G, and is therefore wholly viſible: Whereas before, only the Part O Q, which in the firſt dotted Image is contained between theſe Rays, could be ſeen. And ſo tho' the Object be not quite ſo much magnified, yet it is magnified enough, and the viſible Area very much increaſed by the Interpoſition of this third Glaſs.

N. B. R S is a plain Mirrour to reflect the Light T, for illuminating the Object when tranſparent.

47. The Microſcope conſtructed with three Glaſſes has been executed with great Succeſs, and in many different Forms; all of which have two Parts, *viz.* one *internal*, containing the Glaſſes, and the other *external*, on which the Object is placed, and the Glaſs to illuminate it. Of theſe I contrived a very
Fig. 13. uſeful one for the Pocket, repreſented in *Fig.* 13. where A B C is the upper Part in Wood, Ivory, or Braſs, containing the

two Eye-Glaſſes, *viz.* the Glaſs D E at C, and the other M N at B; the Object Lens C being contained in the Button H, which is raiſed up and down, and thereby adjuſted to its due Diſtance, by means of the Tube or Caſe I, which ſlides in the outward Part or Caſe C D E: In this there are two Apertures, one above where the Object is placed to be viewed in a ſmall concave Lens at G. The other Aperture is the Hole F below, thro' which the Beam of Light T comes in, and is reflected by the Glaſs R S to the Object. It ſtands on a firm Baſis E, and anſwers all the Ends of the largeſt Inſtrument of this Sort, with the utmoſt Eaſe.

48. The SOLAR MICROSCOPE is deſigned to repreſent very ſmall Objects extremely large in a *dark Room*, in the following Manner; A B is a Beam of the Sun's Light falling on a Looking-glaſs D C, ſo adjuſted to a proper Inclination by two Braſs Wheels, that it ſhall reflect the Ray parallel to the Horizon to a large convex Lens E F, which converges them to a Focus; near which is placed the ſmall Object G H, and is by that means greatly illuminated; then a ſmall Lens I is adjuſted by a Screw to a little more than its focal Diſtance from the Object, by which means a very large Image K L is thereby formed on a white Wall or Sheet, on the oppoſite Side of the darkened Room. Fig. 14.

49. The

49. The Power of magnifying in this Inſtrument is thus computed: Suppoſe the ſmall Lens I is diſtant from the Object only $\frac{1}{10}$ of an Inch, when the Image K L is duly formed on the Sheet, and ſuppoſe the Diſtance of the Sheet be 16 Feet from the ſaid Lens; then in 16 Feet there is 192 Inches, and conſequently 1920 Tenths of an Inch; then is the Length of the Object to the Length of the Image, as 1 to 1920, or the Object is magnified 1920 Times in Diameter, and 1920 Times 1920, that is 3086400 Times in Surface, *viz.* above *three Millions of Times*; and 1920 Times three Millions of Times in Solidity. Such is the prodigious and almoſt incredible Power of magnifying in this moſt curious optical Machine!

50. The TELESCOPE of the *refracting Sort* is of two different Structures, *viz.* One of four Lenſes, the other of two. That which has four Lenſes performs its Effects thus; let O B be any diſtant Object to be viewed, and A D the Object-glaſs of the Teleſcope, and B Q the Axis of the Teleſcope. Let B I and O M be two Rays proceeding from the extreme Parts of the Object, and they will terminate the Image I M in the Focus of the Object-glaſs, as is evident from *Art.* 18. and *Fig.* 7. If a convex Lens E F be placed in its focal Diſtance from the Image IM, the Eye will, thro' that Lens, ſee the Image very diſtinctly, but in an inverted

Fig. 15.

Poſition

Poſition (*Art.* 19.). And therefore the View of terreſtrial Objects will be very unpleaſant; but for the heavenly Bodies, which are round, it will do very well; and in this Caſe it is called an *Aſtronomical Teleſcope*.

51. But to ſhew *Land-Objects* erect, another equally convex Glaſs H muſt be placed behind the former E F, at twice its focal Diſtance, that ſo the Rays which Fig. 16. come from the extreme Parts of the Image I and M may croſs each other in the Focus G, and falling upon the Lens H, may form by that Glaſs a *ſecond Image* at its Focus K, which will be erect, or in the ſame Poſition as the Object O B, and may be diſtinctly ſeen by a third Lens L, of the ſame Convexity as the two former, and placed at its focal Diſtance from the ſaid ſecond Image, by an Eye at Q in its Focus on the other Side.

52. Since the Image IM, and the Object O B, are both contained under equal Angles I C M and O C B, they will appear equally large to any Eye placed at the Object-glaſs G. But the Image I M, ſeen thro' the Glaſs E F, is as much larger than what it appears when ſeen through the Lens A D, as the Diſtance C I is greater than the Diſtance I E (*Art.* 41.). And the ſecond Image K N muſt neceſſarily be of the ſame Magnitude with the firſt, becauſe the Ray M F terminates them both after Refraction at F and H, at equal Diſtance from the Axis: And therefore the Image

K N must appear through the Lens at L, just as large as the Image I M will appear thro' the first Lens E F.

53. Suppose then the focal Distance I C of the Object Lens be 3 Feet or 36 Inches, and the focal Distance of the Eye Lens be 2 Inches, then since 2 is contained 18 Times in 36, such a Telescope will *magnify* 18 *Times*. If the Eye Lens were $1\frac{1}{2}$ Inch focal Distance, then $1\frac{1}{2}$) 36 (24, or it will in this Case magnify 24 Times. If it were one Inch only, the Object would be magnified 36 Times, or appear so many Times nearer thro' the Telescope than it does to the naked Eye.

54. There is a Construction of a Telescope *with two Lenses only* to view an Object upright. Of these the Object Lens C D is a *Convex*, as before, but the Eye Lens G E is a *Concave*. And thus supposing A B parallel Rays falling on the Lens C D they will thereby proceed converging to the Focus of the said Lens at F; but if they are intercepted by the Concave G E placed at its focal Distance from the Point F, then will the Rays be refracted thro' it parallel to the Axis, and as such they will produce distinct Vision. See *Art.* 21. and 41.

Fig. 17.

55. The Image is not actually formed by this Telescope, and the Object must appear in its true Position, because there is no *crossing of Rays* in their Passage thro' this Telescope. And if the focal Distance of the

Lenſes in this are the ſame as in the other Teleſcope, the magnifying Power will be the ſame. But the Misfortune of this Teleſcope is, that the *Field of View* is *very ſmall*, and cannot be increaſed but by diminiſhing the magnifying Power, and is therefore ſeldom uſed but in ſhort Lengths, and for viewing *very near Objects*.

56. As the two Sides of a convex Lens contain an Angle ſomewhat in the Manner of the two Sides of a Priſm, it muſt follow, that as in the Priſm, ſo in the Lens, the Rays of Light will be refracted in a different Manner, and to different Parts of the Axis; and therefore when the Image is viewed by an Eye-glaſs with a *very ſhort focal Diſtance*, it muſt appear *obſcure, indiſtinct, and tinged with various Colours*; this Imperfection of refracting Teleſcopes is in a great Meaſure remedied by the Invention of *reflecting Ones*. The Theory of which, in ſhort, is this.

57. Let ABCD repreſent the Tube of a reflecting Teleſcope, EF the large reflecting concave Mirrour, with a Hole HO in the Middle of it, placed at the inmoſt End, and let *gh* be the ſmall Concave placed at the other End upon a Foot or Stem, by which, and a Screw on the Outſide, it is moveable backwards or forwards as Occaſion requires. Let *ab*, *dc*, be two parallel Rays of the Sun's Light, falling on the great Speculum, and by it reflected to its Focus *f*, Fig. 18.

where the Sun's Image will be formed in a ſmall round Spot. If then, by means of the Screw the ſmall Mirrour *g h* be moved to a little more than its focal Diſtance from the Image of the Sun at *f*, the Rays which go from it to the Speculum *g h*, will by it be reflected through the Hole H O in the large one, to a plano-convex Glaſs behind at I K, which will cauſe a ſecond and much larger Image to be formed in the Part L M in the Tube behind; this ſecond Image is viewed by a *Plano-convex* Eye-glaſs, placed in the Part N Q by parallel Rays paſſing thro' a ſmall Hole to the Eye at R.

58. But as this is a very complex and intricate Calculation, I muſt refer the Reader to my *Philoſophia Britannica* for the Method of computing the magnifying Power of this Inſtrument, and ſhall here only obſerve, that it is ſo great that a reflecting Teleſcope, whoſe focal Diſtance of the great Mirrour is any Number of *Inches*, will generally magnify as much as a refracting Teleſcope which is as many *Feet* in Length. I might alſo here obſerve, that this Inſtrument is as well adapted for a Microſcope as a Teleſcope, but this is beſt ſhewn by Experiment, and that in different Ways *.

59. There is a Method of applying either the refracting or reflecting Teleſcope in a

* See more at large the manifold Uſes of a Reflecting Teleſcope in my OPTICAL ESSAYS, lately publiſhed.

dark

Plate II.

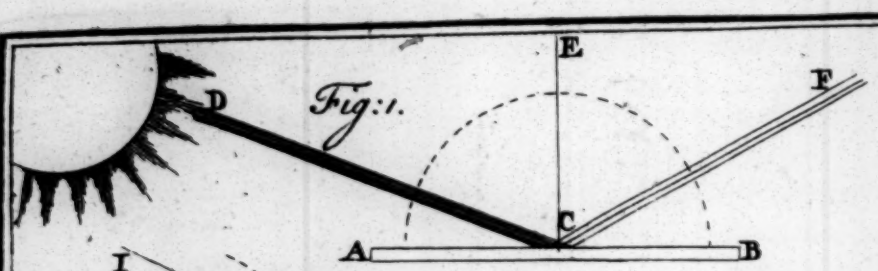


Fig:1.

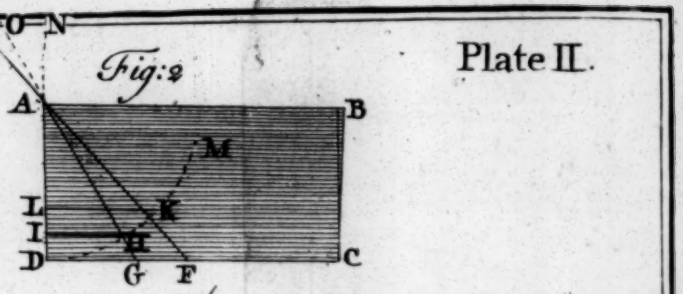


Fig:2.

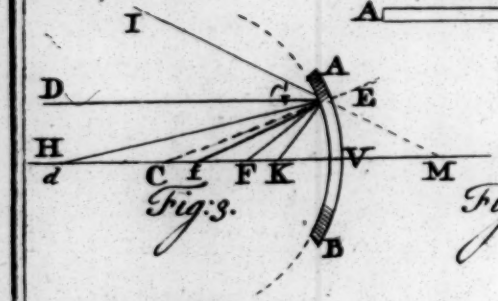


Fig:3.

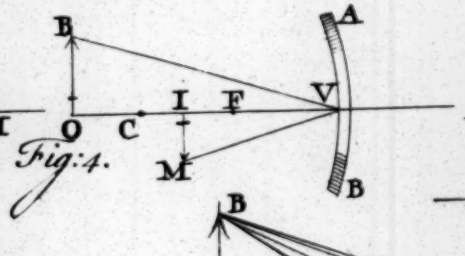


Fig:4.

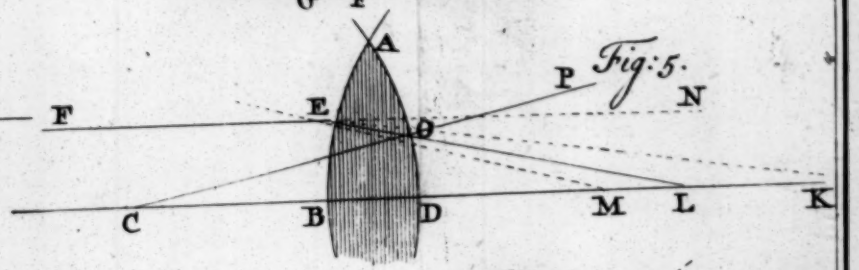


Fig:5.

Fig:6.

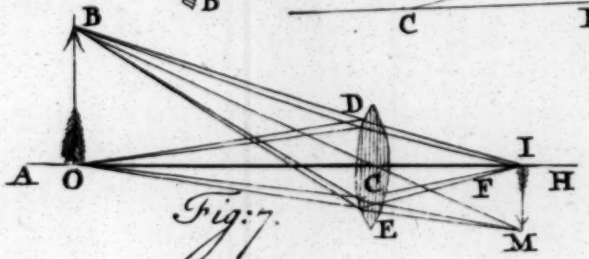


Fig:7.

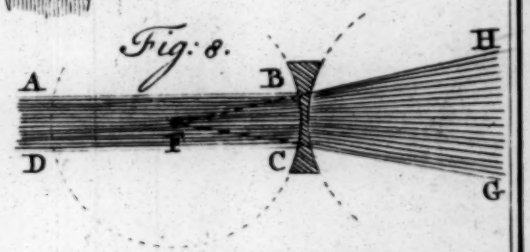


Fig:8.

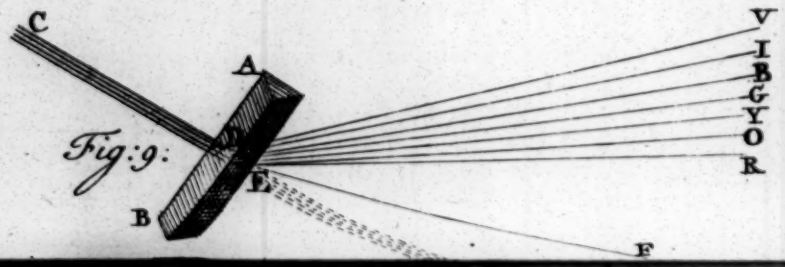


Fig:9.

Fig:10.

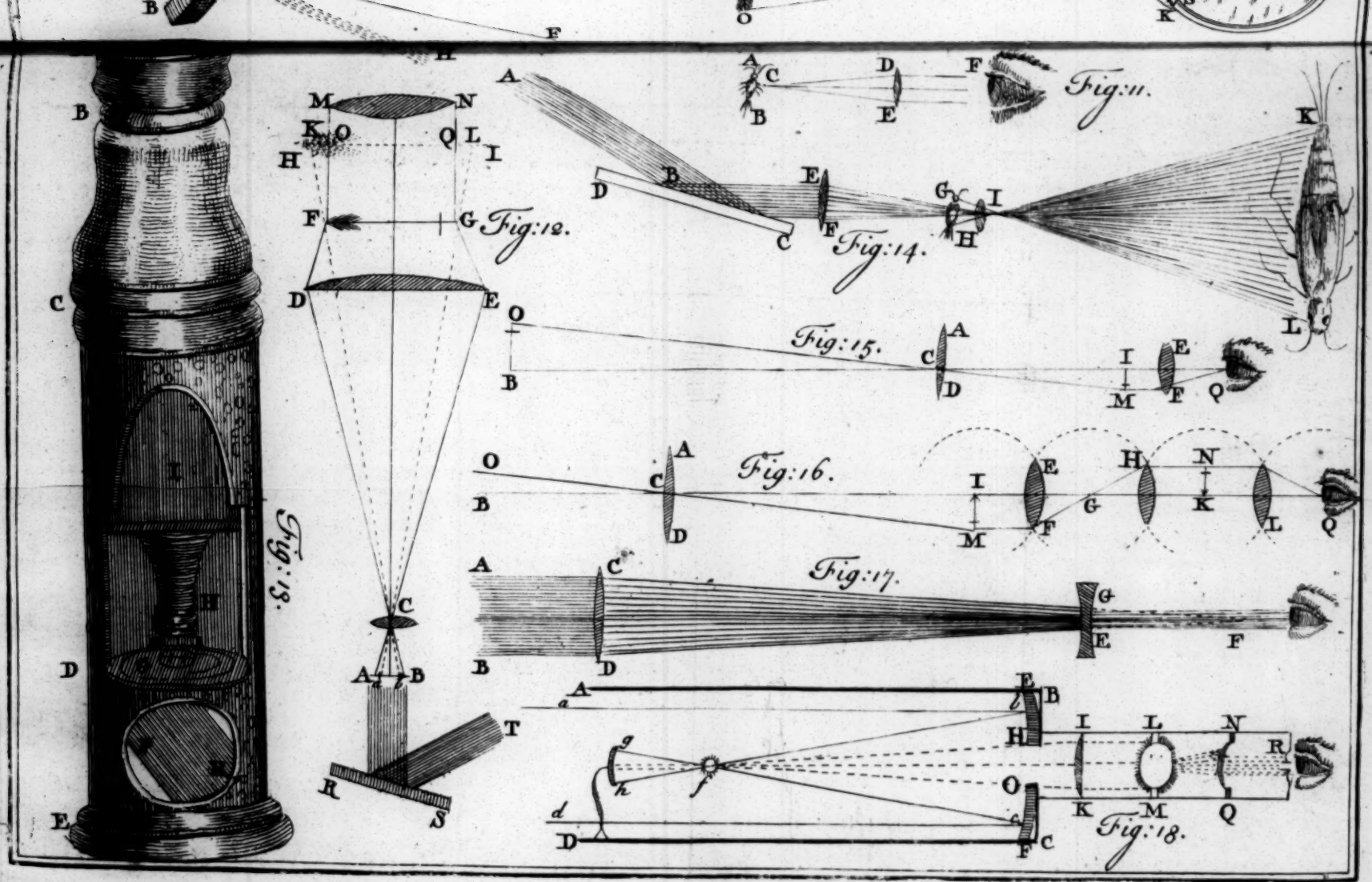


Fig:11.
Fig:12.
Fig:13.
Fig:14.
Fig:15.
Fig:16.
Fig:17.
Fig:18.

dark Room for viewing the *Spots in the Sun*, the *Eclipſes of the Sun*, the *beautiful Colours of the Clouds*, &c. &c. But for this Purpoſe the Refracter is beſt, and may be properly called the *Solar Teleſcope*. This likewiſe we ſhew in all theſe Caſes by Experiments in the *Camera Obſcura*.

SECTION III.

The Nature *and* Properties *of* AIR *explained, the* artificial Production *of* AIR, *of the* TRANSPARENCY, ELASTICITY, *and* GRAVITY *of the* Air, *of* BAROMETERS, THERMOMETERS, *and* HYGROMETERS, *the* Conſtruction *and* Uſe *of a* NEW PORTABLE AIR-PUMP, *a ſelect Number of principal Experiments thereon, to illuſtrate the* Qualities *and* Uſes *of the* Air.

1. THE Buſineſs of this Section will be to diſcourſe of the *Nature*, *Origin*, and *Properties* of AIR, and the Deſcription and Uſe of thoſe *Inſtruments and Machines* by which they are demonſtrated in a *Courſe of Experiments*, according to the modern Improvements and Diſcoveries.

2. The Nature of AIR conſiſts in the following Particulars: (1) Extreme *Subtilty* or *Smallneſs* of its Particles. (2) The *Inviſibility* of its Parts, and the *Tranſparency* thence ariſing. (3) Its *Springineſs* or *Elaſticity*.

ſticity. (4) Its *Weight*, or *Gravity.* (5) The *vivifying Spirit* it contains, ſo neceſſary to the *Life of Animals*, *Vegetation*, &c.

3. As to the firſt Property of Air, which conſiſts in the extreme *Minuteneſs* or *Smallneſs* of its Particles, I obſerved in the firſt Sect. (*Art.* 32.) that this was a neceſſary Conſequence of the Manner in which it was generated, *viz.* by a gentle imperceptible Fermentation in all Bodies, which again proceeds from their *natural Warmth or Heat*, which ariſes wholly from the *Action of Light* imbibed by Bodies (*Sect.* II. *Art.* 5.) by which their Parts are put into an inteſtine Motion; and thoſe on the Surface being conſtantly agitated, are by Degrees thrown out of or beyond the *Sphere of corpuſcular Attraction*, and then immediately repelled from the Body in an Efflux or *Effluvium* of Particles too ſmall to be viſible to the Eye.

4. But in order to ſhew that this is the true and real Method in which Air is generated from Bodies, and at the ſame time to render it viſible to the Eye, the following Experiment has been contrived. ABC is a Glaſs Tube of a conſiderable Length and Diameter, with a very ſmall Hole at the lower End at B. When this Tube is filled full with Water, and ſtopped cloſe on the Top with the Thumb, the Water will not run out at the Hole B, being there ſupported by the Preſſure of the external Air, which is Fig. 1.

greater upward that the Preſſure or Weight of the Water downwards. But if the Thumb be lifted up, it runs out, the Preſſure of the Air being then at Top and Bottom equal.

5. If now the Tube be filled with Water, rendered *acid* by a little *Aqua-fortis*, and a Piece of Chalk D put into it; the Chalk being an *Alkali*, will ferment with the acid Mixture, and thereby generate a very large Quantity of Air, which will be ſeen to riſe thro' the Liquor to the Top of the Tube (which is now cloſe ſtopped with a Cork, as ſhewn in *Fig.* 1.) in innumerable Bubbles, which, breaking above the Surface E F, will become *one uniform elaſtic Body of Air*, which by its Spring will preſs upon the Fluid below, and force it all by Degrees thro' the ſmall Hole at the Bottom B.

6. Now ſince the Tube is at firſt wholly filled with the Fluid, and the Air that is generated forces it all out in Oppoſition to the Preſſure of the outward Air, it plainly appears, *that the Spring of this new generated Air is greater than the Spring of the common Air*, and is in every Reſpect of the ſame Nature with it. And from hence it appears how the common Air is generated from all other Bodies by a like Fermentation, tho' not perceptible to the Eye, as it here is by means of the denſer Medium of the Liquor.

7. From this Experiment we learn, that *Air*, in its natural State is fixed, and makes

a Part of the common Subſtance of Bodies, and is a kind of *natural Cement, which binds the Parts of Matter together*; becauſe we obſerve, that as faſt as the fixed Air is diſcharged and ſet at Liberty, the Particles of the Body loſe their natural Coheſion, and fall off in the Form of a fine Powder or Duſt to the Bottom, and ſo far the Body becomes diſſolved; and the ſame may be obſerved in the common Solution of all other Bodies, in every Sort of diſſolving *Menſtruum*.

8. And what is very obſervable farther in this Experiment is, that this *artificial Air*, in its natural fixed State, makes a great Part of the Subſtance of Bodies. For if we allow $\frac{2}{7}$ *of a Grain for the Weight of a Cubic Inch of Air in its elaſtic State* (as will hereafter appear to be the Caſe) then by this Experiment, tried in a very large Tube, it will be found, that the Air thus produced will amount to a very large Proportion of the Weight of Bodies thus diſſolved. And thus particularly the *Stone in the human Bladder* has been found to yield ſo much Air, *as has amounted to more than half its Weight*.

9. From hence may be deduced the Contrivance of an *artificial Air-Gun*, or *Piſtol in Glaſs*, as A B C E F, conſiſting of a Body G C H, and a Barrel, A B E F, ſomewhat like a Retort: If the Body be filled, the greateſt Part, with the before-mentioned acid Mixture, and a Piece of Chalk D put into it, and Fig. 2.

and then it be charged with a ſmall Piece of Cork with Lead in it, as B E, the Fermentation will produce ſo much *elaſtic Air* above the Surface of the Liquor G H, as at laſt ſhall expel the Lead B E with a prodigious Force, like that of Gunpowder, to a very great Diſtance K.

10. From this Experiment alſo we learn the Reaſon why, in bottled Beer, Ale, Cyder, *&c.* the Corks often fly, and the Bottles burſt, *viz.* with the elaſtic Air generated by a ſlow Fermentation in thoſe Liquors. Alſo the Reaſon of thoſe Eructations of Wind from the Stomach; of *Flatulencies* and cholicky Diſorders in the Bowels, which are all nothing more than the Air generated by Fermentation, ariſing from the Mixture of what we eat and drink, with the natural Juices of the Body.

11. The INVISIBILITY of the Particles of Air, is the Cauſe of its *Tranſparency*; and this is a neceſſary Quality, inaſmuch as we could not have been able to have diſcerned Objects through it with any Degree of Clearneſs and Diſtinction, had it been in any Meaſure opaque. This appears by viewing Objects through Teleſcopes of a large magnifying Power, which at the ſame time magnify the Particles or Body of Air, and cauſe Objects ſeen through it to appear very miſty and confuſed. Hence alſo it appears, that the

the Air thus magnified ſets Bounds to the Improvement of Teleſcopes.

12. The Body of Air, conſidered as a Sphere of elaſtic Vapours, ſublimed from Bodies, extends or expands itſelf to a very great Diſtance or Height from the Earth every way; and is every-where of a different decreaſing Denſity. For the Air being every-where compreſſed with the Weight of the ſuper-incumbent Air, muſt have its Denſity proportional to that Preſſure; and therefore decreaſing upwards in the ſame Ratio as the Air's Height, Gravity, or Preſſure decreaſes.

13. Were the Denſity of the Air every-where the ſame, it would be very eaſy to determine its Height by the following Experiment. ABCD is a Vial filled with Water to the Height E F, in which is immerſed a Glaſs Tube I G, open at both Ends, and cemented to the Vial at A D, to cut off the Communication of Air. This done, a little Air is blown thro' the Tube, which mixing with the Air in the Part A E F D, will condenſe it, and of courſe increaſe its Spring or Preſſure; this will raiſe a Column of Water into the Tube to the Height H, ſuch that its Weight, together with the Weight of the Column of Air above it, be equal to the Spring of the included Air; and then an *Equilibrium* between them will enſue. Fig. 3.

14. If now the Vial, thus prepared, be carried up any high Place, as a *Tower*, *Hill*, &c.

&c. it will be ſeen, that for every 72 Feet you advance, the Surface H will riſe *juſt one Inch* in the Tube. Now ſince this one Inch of Water riſes to compenſate the Deficiency of Preſſure in the Column of Air over it, now ſhortened 72 Feet; and ſince (as we ſhall make appear hereafter) the whole Weight of the Air will raiſe a Column of Water 32 Feet, or 384 Inches, it is evident if we multiply 384 by 72, it will give the Number of Feet (*viz.* 27648) which would aſſign the Height of the Atmoſphere uniformly denſe, which is about 5 $\frac{1}{4}$ Miles.

15. This Experiment alſo moſt accurately aſſigns the *comparative Gravities of Air and Water*; for ſince it appears, that one Inch of Water countervails 72 Feet, or 864 Inches of Air, and the Gravities of Fluids acting againſt each other are inverſely as their Altitudes (as hereafter appears) it follows, *that the Denſity of Air is to that of Water, as* 1 *to* 864 *preciſely*.

16. This Inſtrument alſo preſents us with one of the moſt eaſy and perfect extemporaneous *Thermometers* that can be contrived. For ſince the Column of Water G H is ſupported by the very yielding and tender Spring of the included Air preſſing upon the Surface E F, it will *riſe and fall* with the *leaſt Expanſion or Contraction* of that Body of Air by *Heat and Cold*. Thus if the *Hand* be applied to the Vial, it will riſe ſeveral Inches; and

and if it be immerſed in *cold Water*, it will deſcend through many more. Thus alſo it is fitted for diſcovering the *ſmall Differences of Heat and Cold* in different Rooms of a Houſe. Thus alſo it is applicable to *Stoves*, *Hot-houſes*, *Hot-beds*, &c.

17. But, as I ſaid, it is fit only for *extemporary* or *preſent Uſe*; becauſe the upper Surface H being preſſed with the Air above it, if the Gravity of the Air be altered, it will riſe and fall by that Means, tho' we ſuppoſe the Warmth of the Room to remain the ſame all the while. And therefore it cannot be depended upon as a *Thermometer* for any long Time together.

18. And as the *Heat and Cold of Air* is the Baſis of the curious and uſeful *Invention of Thermometers*, which are Inſtruments to meaſure the various Degrees thereof, I ſhall explain in a few Words the Nature and Uſe of them. It is well known, that all Bodies, whether *fluid or ſolid*, *expand with Heat*, and *contract with Cold*, and therefore may be made uſe of for this Purpoſe. But *Fluids* are the moſt proper Subject; and amongſt them, *Spirits*, *Oil*, and *Mercury* have the Preference, but eſpecially the latter, on the following Accounts. (1) *Mercury* does not filth or foul the Tube in which it is contained, as tinged Spirits and Oil do. (2) It expands and contracts much more ſpeedily than either of the other. (3) It is ſuſceptible

tible of vaſtly greater Degrees of Heat and Cold than any other Fluid whatſoever.

Fig. 4. 19. The *Mercurial Thermometer* is a fine capillary Tube AB, with a round or oblong Bulb BC. filled with Mercury to a proper Height as F. Here, ſince the Bore of the Tube is exceeding ſmall, the Motion of the Mercury up and down in it, by the leaſt Expanſion or Contraction of that in the Bulb, will be very ſenſible; and a Scale of equal Parts DE, being placed by it, the various Degrees of Heat and Cold will be eaſily diſcerned and compared by the Numbers in the Scale, againſt which the Point F ſhall at any Time ſtand.

20. Since *Heat and Cold* are only relative Terms or Ideas, there is a *common Standard* or *Boundary* to which they muſt be referred, and from whence their Quantity on each Side muſt be eſtimated, by the Parts of the Scale affixed to it. And this common Limit of *Heat and Cold* can be no other, with reſpect to us, than that *particular Degree* or *Temperature* of the Air when we ſay, *it is neither warm nor cold*; or that which is equal to the natural Warmth of the external Part of the Body.

21. Now from this *Point of Temperature* the Diviſions of the Scale ought to begin, as in the Figure, and to be continued both Ways; and then the various Degrees of Heat may be compared, as to their Exceſſes or Differences

Differences from that of Temperature, very eaſily, thus: If any Degree of Heat A, ſhall raiſe the Mercury 10 Parts, and another Degree B, raiſe it 20, and a Third Degree C, raiſe it 30, then will theſe Numbers 10, 20, and 30, or 1, 2, 3, undoubtedly expreſs the Ratios of the Intenſities of thoſe Degrees of Heat, or the Senſations we have of their Effects.

22. Thus, on the other Hand, we may judge of the various Degrees of Cold, or rather of thoſe Degrees of Warmth which are *leſs* than *temperate*, or that of the Hand. If it *freeze* when the Mercury is 10 Degrees below temperate, it will be *twice as cold* when it ſtands 20 Degrees below, and ſo on. Tho' this be a Method ſufficient for one's own private Uſe, yet when it is neceſſary to communicate one's Obſervations of this Kind to others who make the ſame at a Diſtance, and upon *different Thermometers*, there ought to be one common Number of Parts agreed upon between *two ſuch Points as are conſtant* in all Thermometers; and it is found, that none are more ſo than the Points of *freezing* and *boiling Water*.

23. This being conſidered, and the Learned having generally a Regard to *Farenheit's Scale*, in which the *freezing Point* is at 32, and that of *boiling Water* 212, ſo that between them there is 180; if then the ſame Number 180 be reckoned between the ſame

two

two Points in any other Scale, they may all be compared with this, and conſequently with one another. Or thus, by the *Rule of Three:* Suppoſe the Thermometer in the Figure contains 80 Degrees between thoſe two Points, and that any particular Heat raiſes the Quickſilver to 20 above *freezing*, then ſay, as 80 : 20 : : 180 : 45; then to 45 add 32, and the Sum is 77, which is the Number to which the Mercury ſtands in *Farenheit's Scale.*

24. The Air has another Quality, *viz.* of various Degrees of *Moiſture and Dryneſs*, as it is always more or leſs replete with *aqueous Particles* or *watry Vapours*; and ſince the human Frame is thereby very much affected in regard to Health, it has occaſioned the Contrivance of various Inſtruments called HYGROMETERS, for meaſuring the Degrees thereof, of which I have elſewhere given a large Account. But I ſhall deſcribe one of a late Invention, which ſeems well calculated to anſwer this Purpoſe. It has been obſerved, that Boards ſwell and contract very much *width-ways*, by the Moiſture and Dryneſs of the Air; and from thence it was inferred, if a Board was ſawed acroſs the Grain into ſeveral Pieces about an Inch wide, and theſe Pieces all glued together at their Ends, they would make one long Slip that would admit of a conſiderable Degree of Expanſion and Con-

Contraction in Length, ſuch as repreſented by A B in the Figure.

25. If this Piece be fixed in an upright Poſition, with a Cord D E going over a moveable Pully C, carrying an Index I over the graduated Limb of a Quadrant G H, and tended with a Weight F, it is evident, that as the Piece A B extends in Length by the Moiſture entering the Pores of it, the Index muſt go forwards; and as it contracts with Dryneſs, the Index will move backwards, and thereby meaſure the various Degrees of theſe Qualities of the Air. The Piece ſhould be firſt put up as dry as poſſible, and the Index then ſet to the Beginning of the Degrees at G, and then the ſeveral Degrees of Moiſture will afterwards move it from thence towards H. But this Piece of Wood is applicable to greater Perfection in an Inſtrument called the *Pyrometer*, to be hereafter deſcribed. Fig. 5.

26. The Air is alſo a very heavy or ponderous Body; for its Parts, tho' ſmall, gravitate in this their ſeparate State, as much as when fixed in Bodies, by virtue of the Earth's Attraction. And therefore, like all other Bodies, *the Air gravitates in proportion to its Quantity of Matter.*

27. But, as was obſerved in the firſt Section, the Air conſiſts of very different Kinds of Matter, which makes it ſometimes *lighter*, ſometimes *heavier*, according to its conſti-

tuent Matter. Thus when the Air abounds with *aqueous Parts*, it will become much lighter than when it conſiſts of Particles derived from dry, ſolid, heavy Bodies, which makes the drieſt, fineſt, and *heavieſt Air*. The Reaſon of this has been ſhewn in *Sect.* I. *Art.* 35. *Fig.* 8.

28. As the *Air* is by Nature appointed the neceſſary Means of Reſpiration, and as an elaſtic heavy Air is of much more Force to *expand the Lungs*, and to *impregnate the Blood with its enlivening* Spirit, than the Air which is weaker and lighter, it imports us greatly to be well acquainted with the *Air's Gravity*, and the *Alterations it* continually undergoes in that reſpect, eſpecially too, as it muſt neceſſarily have a Relation to the State of the *Weather*, and *all its Variations*, of which it is in a great Meaſure the Cauſe (See *Sect.* I. *Art.* 36.); I ſay, upon theſe Accounts, it is no Wonder if ingenious Men have long been in the Purſuit of the moſt eaſy and expreſſive Methods and Inſtruments to indicate this Affair.

29. And various have been their Inventions for this Purpoſe; and BAROMETERS have been multiplied in numerous different Forms. But after having examined them all, I am firmly perſuaded there is none that comes up to that which was firſt of all invented, either for *Eaſineſs of Structure, Simplicity of Parts, and Accurateneſs of Uſe*; and

and is made in the following Manner. A B is a Glaſs Tube of 34 Inches Length, and whoſe Bore is about ¼ of an Inch Diameter. It is hermetically cloſed at the End A, and at the open End B it is filled quite full of very clean, pure Mercury; then whilſt it is thus full, it is inverted, with the End B ſtopped, into a wide Baſon of Mercury ECDF, and then the End B being unſtopped, the Mercury will ſubſide from the Top A, and ſtand at a certain Height BI in the Tube. Fig. 6.

30. By this Means the Space above the Mercury A I is left devoid of Air, or is a *Vacuum*; and the Column of Mercury in the Tube B I, is ſuſtained ſolely by the Gravity of the Air, or its Preſſure on the Mercury in the Baſon, which ariſes from thence, as evidently appears from an Experiment of taking the Air away by the Pump, and in proportion as it is exhauſted, the Mercury will ſink towards the Bottom. *This Column of Mercury therefore is an Equipoiſe to a Column of Air of the ſame Baſe and Height of the Atmoſphere*, and of Courſe the Weight of both muſt be the ſame.

31. Therefore whenever the *Gravity of the Air alters*, the Column B I will alſo *alter its Height*, and ſo when the Air becomes *heavier*, it will riſe *higher*, and as the Air becomes *lighter*, it will ſink *lower*: And it is found by Experience, that when lighteſt of all, it ſinks not much below the Height

of 28 Inches, and when *heavieſt*, it riſes not higher than 31 Inches; and it very rarely comes to either of theſe Extremes, the *mean Height* being nearly 29 $\frac{1}{2}$ Inches. All which is eaſily obſerved by a Scale of Inches applied to the Tube, as is repreſented in the Figure.

32. If the Tube A B were of a ſquare Form, and juſt a *ſquare Inch* Area in the Bore, the Mercury would riſe to the ſame Height, at a Mean, 29 Inches; ſo that in ſuch a Tube, there would be 29 cubic Inches of Mercury; and every ſuch cubic Inch weighs 8 $\frac{1}{10}$ oz. Avoirdupois; therefore the Weight of ſuch a Column of Mercury, and conſequently of a Column of Air of the ſame Baſe, will be equal to about 14 lb. Weight; and ſo upon every *ſquare Foot*, it will be 14 Times 144, or 2016 lb. and ſomewhat more; and if we allow about 14 $\frac{1}{2}$ ſquare Feet upon the Surface of a middle-ſized Man, it will follow, that ſuch a Man ſuſtains a Preſſure of Air equal to 2016 Times 14 $\frac{1}{2}$ lb. or nearly 30000 lb. which is nearly 14 Tons.

33. The Reaſon why we are not ſenſible of ſo very great a Preſſure, is becauſe our Bodies are filled with Air throughout, and the Spring of the internal Air is every way equal to the Preſſure; and therefore every Part of the Body being acted upon by a Force on every Side equal, it cannot be ſenſible of any Force at all, either of Spring or Preſſure; but if one of thoſe Forces be ſuſpended in

any ſmall Degree, the other becomes immediately very ſenſible, as we ſhew by an Experiment on the Pump to explain the Nature of *Cupping*.

34. Hence ſince the Difference between the leaſt and greateſt Height of the Quickſilver in the Tube is 3 Inches, it follows, that when the Air is heavieſt, we ſuſtain a Preſſure of more than a tenth Part of the Whole, greater than when it is lighteſt, which is more than a Ton Weight. And therefore it is eaſy to ſee the Reaſon why a *light Air* affects *aſthmatic People*, and other *Valetudinarians*, in ſo very ſenſible a Manner, as we find by Experience it always does. The Air when ſo light, not having the Force to *expand the Lungs*, to *brace the Fibres*, to *promote the Circulation*, to *open Obſtructions*, and *produce a free Perſpiration*, as when it has a greater *Weight and Elaſticity*.

35. We are by this Inſtrument moreover enabled to predict the *Alteration of Weather*; for when we ſee the Mercury falling, we know the *Air is lighter*; we know by that it muſt be filled with aqueous Particles; we know alſo from thence that Clouds, Storms, Rain, and Wind muſt enſue; and the contrary. And hence the *great Uſe*, yea *Neceſſity* of theſe Inſtruments to all who are any way concerned with the *different State and Alteration of the Weather*. And it is not difficult

for every one to find that he is more or leſs affected by it.

36. Theſe are the different Inſtruments that indicate the various Qualities of the Air. But the *Grand Machine* of all, by which the ſeveral Properties of Air are in a moſt wonderful and entertaining Manner rendered ſenſible to us, is the AIR-PUMP. This Machine has undergone various Forms and Changes ſince its firſt Invention by *Otto Gueric*, a *German*; by *Boyle*, *Haukeſby*, *Davenport*, &c. But as I have contrived one different from them all, far more conciſe and eaſy to be uſed, I ſhall here give a Deſcription of it, as follows. A B is the Frame or Head, in which is contained a Wheel, which moves the two Piſtons C, D, up and down alternately in the Braſs Barrels E F, which are ſtrongly ſcrewed down on the two Pillars G H, fixed in the Bed or Bottom Part I K. On this Part in the Middle is let in a large ſmooth Braſs Plate, with a Hole in the Middle, upon which Plate the *Receiver* M N is placed. From this Hole under the Receiver there is a Perforation or Canal through the Braſs to the fore Part O, where there is adapted a Screw to let the Air into the Receiver when exhauſted.

Fig. 7.

37. From the above-mentioned Canal, there is alſo a Perforation through the Braſs to the Center of the Baſis of each Barrel, in which Center there are Valves opening

ing upwards to give Paſſage for the Air into the Barrels; and in each Piſton there is another Valve opening upwards alſo, that the Air now in the lower Part of the Barrel may eſcape that way out into the common Air. Hence the *Rationale* of Working in this Pump muſt be very plain.

38. For each Piſton, being nicely fitted to the Barrel, and working in Leather and Oil, is very *Air-tight*; and therefore when lifted from the Bottom of the Barrel, the Column of Air above is lifted up, or off from the Valve; and the little remaining Air in the Barrel below being thus greatly rarified, its Spring is but weak, and therefore the Air from the Receiver muſt neceſſarily ruſh in under the Valve to make the Air in the Barrel of the ſame Denſity. Then when the Piſton is forced down, the Air below can't go back, but will be condenſed and ruſh upwards, and get under the Valve in the Piſton into the open Air. And thus each Stroke of the Piſtons diminiſhes the Air in the Receiver till the Whole be nearly exhauſted.

39. On the Middle between the two Barrels there is a Hole in the Braſs communicating with the Receiver, and over this Hole is placed a ſmall Receiver P Q, and under it a ſmall Baſon R with Mercury, in which a ſmall Tube R S, ſealed at the End S, and filled with Mercury, is inverted. And as the Air is taken out of this ſmall Receiver

at the ſame time as the large one is exhauſted, the Approach towards a *Vacuum* will be clearly ſeen by the gradual Deſcent of the Mercury out of the Tube into the Baſon. And ſuch is the Structure and Form of an *Air Pump*, that *contains no Parts but what are eſſential, and therefore cannot admit of farther Reduction*. Indeed one Barrel may be made to anſwer the End of two; but thoſe who prefer that Simplicity of Structure will find they muſt pay dear for it.

40. I ſhall now proceed to give an Account of the capital Experiments which are ſhewn upon this Pump; and firſt, a ſmall Glaſs is inverted over the Hole of the Plate, and the Air within exhauſted; it is then preſſed very faſt to the Plate by the Weight of the incumbent Air, and requires a great Force to pull it up.

41. That this is not owing to any thing within the Glaſs, drawing it down thro' the Hole, and which is commonly called *Suction*, is thus proved; let the Glaſs be ſet inverted on one Side the Hole, and covered with a Receiver; then upon exhauſting, the Air will get out of the ſmall Glaſs by its Spring; when the Air is let in again, it will fall upon the ſmall Glaſs, and preſs it down as faſt as before.

42. The Manner in which the Air diſcharges itſelf from any Body, is ſhewn by a large empty Glaſs Bubble with a Neck, immerſed in a Glaſs of Water; and then covered

vered with a Receiver. Upon exhauſting the Air will be ſeen to throw itſelf out through the Water in a pleaſant Manner, and upon letting the Air in again it will fall on the Water, and force it into the Bubble, ſo that the remaining Air is now compreſſed into a very ſmall Space at the Top.

43. Then to ſhew that the *Force of the Air's Spring is equal to that of its Preſſure*, this Glaſs Bubble of Water and Air is placed under the Receiver upon an empty Glaſs; and, upon exhauſting the Air, the Air Bubble above the Water will expand itſelf by Degrees, and all the Water will deſcend which was driven into it by the Air's Preſſure.

44. In like Manner, there is a Bubble of Air contained in the great End of an Egg, betwixt the Skin and the Shell; if therefore a Hole be made in the little End, and the Egg placed on a Glaſs under the Receiver, it will appear, that upon pumping, the Air will expand itſelf ſo far as to drive out all the Contents of the Egg thro' the Hole in the little End.

45. And by taking off half the Shell, putting the Remainder under the Receiver, and exhauſting the Air, the Air that is contained under the Skin (or *Putamen*) will raiſe it up and protrude it ſometimes ſo far out as to reſemble an entire Egg.

46. If an Egg be put into a ſmall Jar of Water, and covered with the Recipient, upon exhauſting you will ſee the Air in a very

very beautiful Manner riſe in little Jets or Streams through the Water from the Pores of the Egg; which ſhews how the Air by the natural Heat of the Weather gradually eſcapes from the Egg, by which Means it becomes by degrees *ſtale, putrid, and addle*; and therefore to preſerve Eggs good for a long Time, the beſt way is to varniſh them over with a hard Varniſh, which will glue up the Pores, and prevent the Air in the Egg making its Eſcape.

47. If a ſhrivelled Apple be placed under the Receiver, and the Air exhauſted, the Air contained in the Apple will expand itſelf and the Apple, and thereby cauſe the Wrinkles to diſappear, and the Apple will now appear plump and fair as when firſt gathered. Upon letting in the Air, the Apple becomes again ſhrivelled, and more ſo than at firſt.

48. If ſuch an Apple be pricked full of Holes with a Pin, and put into the Jar of Water under the Receiver, and the Air exhauſted, then great Numbers of fine *Jets of Air* will be ſeen to riſe from the Apple through the Water, as before in the Egg; which will all diſappear by letting the Air in again.

49. If a Jar of clear Water be placed under the Receiver and the Air exhauſted, the Bubbles of Air contained in the Water will now begin to expand themſelves, and ariſe

in great Plenty from all Parts of the Water, and in a very viſible Manner.

50. If a Jar of new Beer or Ale be placed under the Receiver, upon exhauſting, the Air in the Beer will riſe in a very copious Manner from all Parts, and expand into innumerable Bubbles, which, as they are lined with the viſcid Particles of the Beer, will be thereby prevented from burſting, as they do in Water, and by this Means they will appear in the Form of a *large frothy Head* to the Top of the Glaſs.

51. If ſome very hot Water be put into a Glaſs Jar or Vial, and placed under the Receiver when the Air is ſufficiently drawn out, the Heat will cauſe the Air in the Water to expand itſelf into ſuch large Volumes or Bubbles, and with ſo much Violence, as will put the Water into a great Agitation, and produce the Appearance of *Boiling* to a ſurpriſing Degree. A much leſs Degree of Heat being now ſufficient for that Purpoſe, than when it is under the Compreſſion of the Atmoſphere, over the Fire.

52. If a Piece of Wood of any Sort be fixed to a Weight, and immerſed in a Jar of Water under the Receiver, then upon exhauſting, the Air contained in the Pores of the Wood will be ſeen to ariſe from it in ſo great a Quantity and ſuch fine Streams, as nearly reſembles the Smoke from a Chimney.

53. If

53. If a long Piece of Wood be fixed with Leathers to the Top of an open Receiver, ſo that one Part be out, and the other in the Receiver, and immerſed in a Glaſs of Water; then putting your Thumb upon the Top of the Wood to ſhut off the Air, begin to exhauſt, and the Air contained in the Pores will be ſeen to ruſh thro' the Water as before; but now lift up your Thumb, and you'll ſee a vaſt Quantity of Air flow thro' all the Length of the Wood from without. And by moving the Thumb off and on, ſeveral Times, the Influx of Air will as often appear, and be as often interrupted. And by this Experiment it appears, that there are *no lateral Pores* in the Wood by which the Air can enter into the Receiver.

54. Again, fitting a Piece of Wood with Cement into one End of a wooden Funnel, and placing it with Leathers on the Top of the ſame Receiver, fill the upper and open Part of the Ferril with Mercury, then exhauſt the Air from within, and the Air preſſing on the Mercury without will force it thro' the Pores of the Wood in ſuch fine Streams as will repreſent a *beautiful Shower of Mercury* in the Receiver.

55. Let a Piece of Wood be cut ſmooth at each End, and immerſed in a ſmall Baſon of Mercury under the Receiver, upon exhauſting, the Air will all fly out of the Pores through the Mercury; and letting the Air in again,

again, it will fall with ſo much Force upon the Mercury as to inject it thro' all the Pores of the Wood ſo very nicely, that the Wood will now appear quite *blue*, and be much *heavier than before*.

56. If a Bladder nearly emptied of Air, and faſt tied, be put under the Receiver, and the Air extracted; the ſmall Quantity of Air remaining in the Bladder will expand it by Degrees, and at laſt fill the Whole to its utmoſt Dimenſions. And indeed the ſmalleſt Quantity of Air will fill the largeſt Space by Expanſion.

57. If the Hand be laid upon the Top of an open Receiver, as the Air is exhauſting, you will obſerve and very ſenſibly feel the Spring of the Air in the Hand, forcing the Fleſh down into the Glaſs; alſo the Weight of the Air on the Back of the Hand will have a viſible Effect in preſſing down the Skin and Fleſh between the metacarpal Bones. This Experiment fully explains the Nature of *Cupping*.

58. The Weight of the Air is more directly ſhewn, and its Quantity eſtimated, by weighing it in a Balance as we do other Bodies. Thus a *Florence* Flaſk with a Valve fitted on the Top is exhauſted under the Receiver, and, while thus empty, it is equipoiſed with Weights in a fine Hydroſtatic Balance; then lifting up the Valve, the Air re-enters the Flaſk, and, by its Weight,

carries it down; then the Number of Grains put into the other Scale to reſtore the Equilibrium is the Weight of that Air which fills the Bottle. And this I find to be nearly *Eight Grains* for *a Pint*, or a *Dram* for *a Gallon*; or an *Ounce Troy* for *a Buſhel*.

59. To ſhew the great Force of Compreſſion, I take *two hollow Braſs Hemiſpheres* of 4 Inches Diameter, which contain a circular Area of 12 $\frac{1}{2}$ ſquare Inches; theſe being properly put together and exhauſted, will require the Force of *two ſtrong Men* to pull them aſunder; or 180lb. to ſeparate them on the *Steel-Yard*; which is about 15 lb. to a *ſquare Inch* (See *Art.* 32.).

60. The *Air* is the Medium that *propagates Sound*; as appears by placing a Bell under the Receiver; for then when it is rung, you ſcarcely hear the Sound, even tho' the Receiver be not exhauſted; but when the Air is drawn out, you can hear no Sound at all. SOUND conſiſting in nothing more than a *pulſive Motion* of the Air, excited by the Tremors of the ſounding Body, and, ſtriking upon the Drum of the Ear, puts the internal Air into Motion upon the Expanſion of the *auditory Nerve*, by which Means the Ideas of Sound are raiſed in the Mind.

61. The Air is alſo neceſſary for *Fire* and *Flame*; ſince a Candle, live Coal, *&c.* inſtantly go out under the exhauſted Receiver. Alſo *Gunpowder* will not explode or flaſh *in vacuo*,

vacuo, nor any *Sparks of Fire* be ſeen from the *Flint and Steel* in that Caſe.

62. But the greateſt Neceſſity and Importance of Air is for *animal Reſpiration*; eſpecially all the larger Sort, which immediately die upon exhauſting it; and though *Inſects*, *Reptiles*, *aquatic Animals*, &c. will not die (at leaſt under a long Time) *in Vacuo*; yet they ſeem to undergo ſome very painful Senſations, when the Air is taken from them, as is evident from divers Experiments of this Sort.

63. Though a common Animal ſoon dies by exhauſting the Air, yet if it be let in again before the Blood becomes ſtagnant, it will expand the Lungs, and permit the Blood to circulate through them again; upon which the Animal will revive, and appear in a few Minutes but little the worſe for ſuch a *temporary Death*.

64. If a Receiver be exhauſted, and the Air let in again through a *Charcoal Fire*, it will thereby have its *vivifying Quality* deſtroyed, for a Candle inſtantly goes out in it, and a Bird falls down dead very ſuddenly; it ſeems to be infected like that we call *Damps* in the Bottoms of deep Pits, Mines, &c. which produce the ſame Kind of Effects. And it is known by too many Inſtances, how deleterious a *Charcoal* Fire renders the Air of a common Room when confined. It is remarkable that no common *Coal*

or

or *Wood Fire* will produce this Effect; and that the Air in paſſing thro' the *Charcoal* Fire has none of its ſenſible Qualities altered.

65. Laſtly, that the lighteſt Body falls as ſoon as the heavieſt *in vacuo*, is ſhewn by a Guinea and Feather falling in the ſame Time from the Top to the Bottom of a tall Receiver. For where there is no *reſiſting Medium*, there can be nothing to cauſe any Difference in the Time of the Fall, ſince every Particle in both Bodies being urged with the ſame Force downwards, they muſt neceſſarily all go with the *ſame Velocity*.

66. Theſe are moſt of the capital Experiments of the *Air-Pump*, and demonſtrate all the important Properties of the Air. They who would ſee much more may have Recourſe to my *Philoſophia Britannica*. I ſhall conclude this Part with obſerving to the Reader, that the Way in which the Air is exhauſted, may be rendered viſible to the Eye by the following Contrivance. Let A B C D be a Tube of Glaſs, ſcrewed in at the Bottom to a Receiver R, in form of a Cupping-Glaſs. In this Glaſs Barrel let Water ſtand over the Valve V to the Height of about two Inches C E F D. Alſo let Water be put over the Piſton G H I K, to the Height L M; then it is evident, that when the Piſton is placed on the Surface of

Fig. 8.

Water

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Plate III.

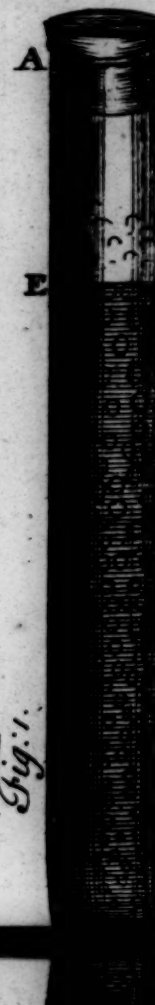


Fig: 1.

Fig: 2.

Fig: 3.

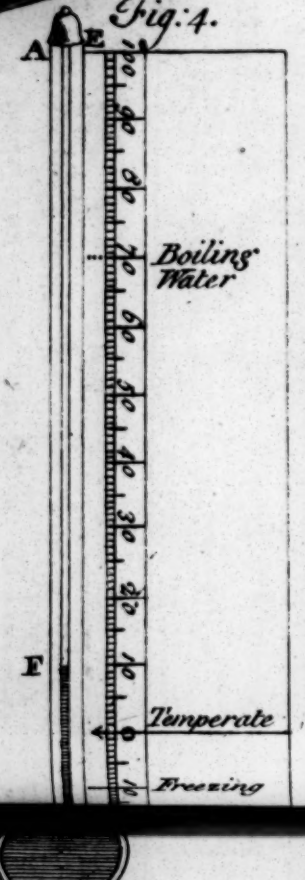


Fig: 4.

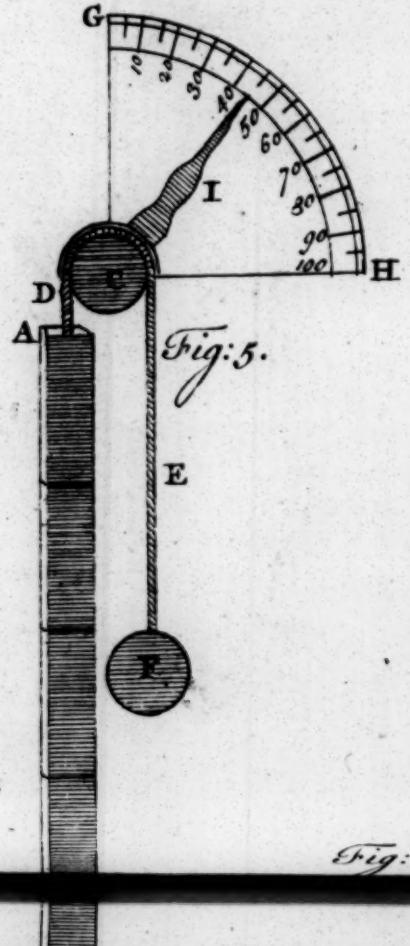


Fig: 5.

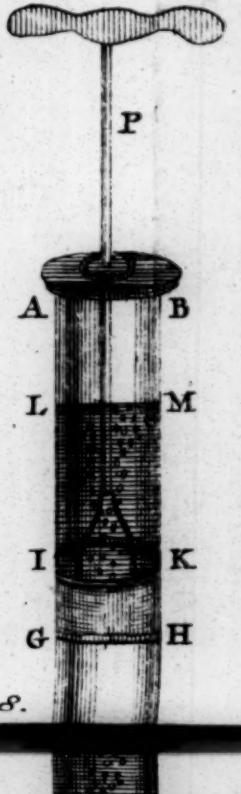
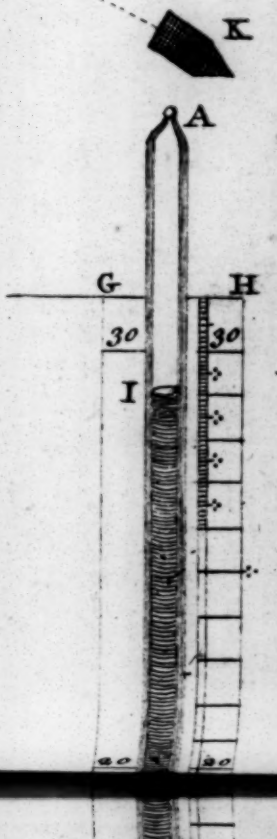


Fig: 8.



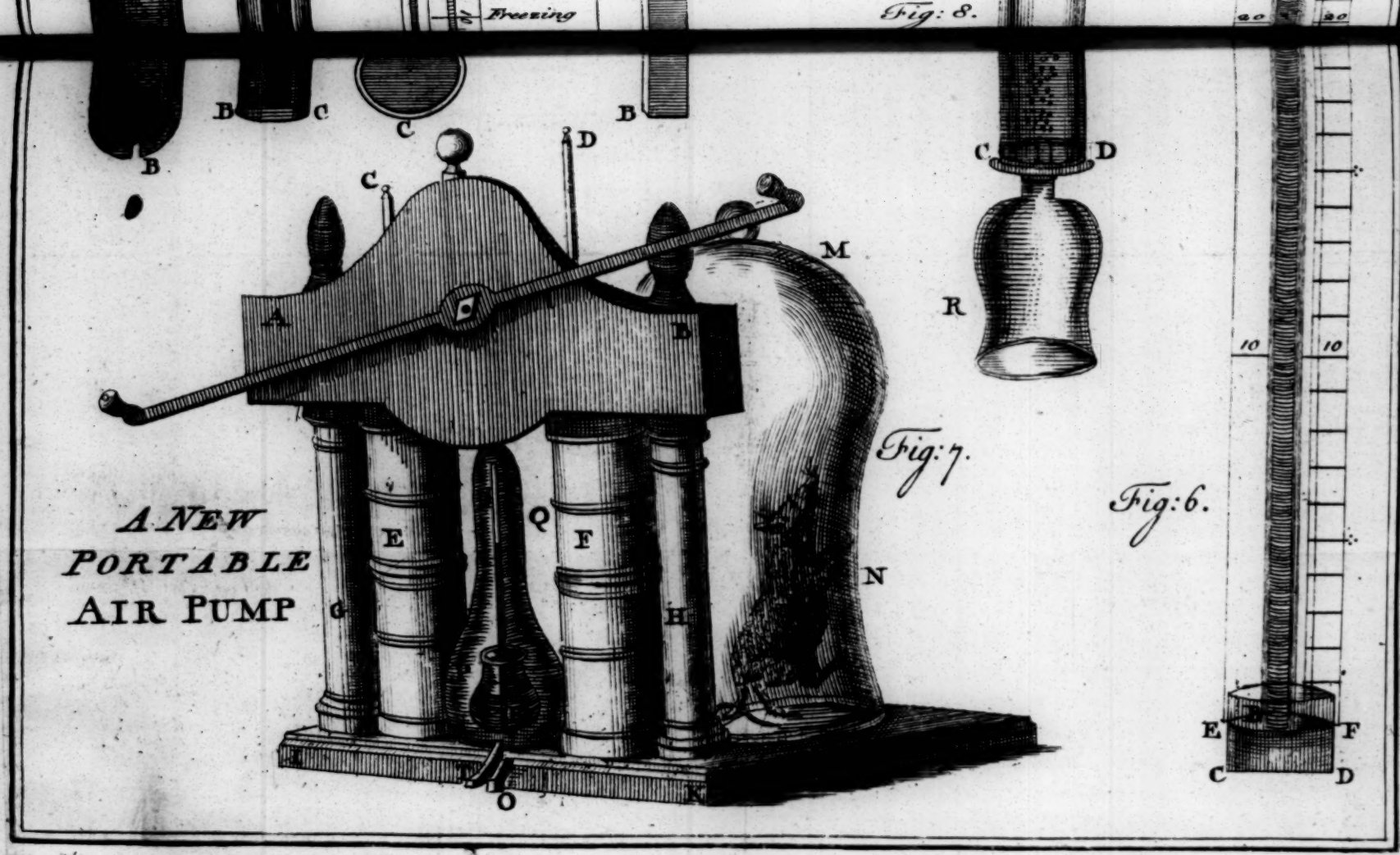


Fig: 8.

Fig: 7.

Fig: 6.

A NEW PORTABLE AIR PUMP

Water below at E F, and raiſed up again, the Air from the Receiver R will ruſh up thro' the Valve V, and all the Water above it in a very pleaſant and viſible Manner, to fill the Space below the Piſton. This Air muſt again, upon the Deſcent of the Piſton, riſe up thro' its Valve, and all the Water above, as before; all which is ſo plainly repreſented in the Figure as to require no further Deſcription.

SECTION IV.

Of the various SYSTEMS *of the* WORLD. *The* COPERNICAN *or* SOLAR SYSTEM *proved to be the only true one. The ſame explained at large. The* Diſpoſition, Number, Magnitudes, Motion, *and* Diſtances, *of the* HEAVENLY BODIES. *The Nature of* DAY *and* NIGHT; *the Viciſſitude of the* SEASONS; *the Nature of* ECLIPSES; *the Theory of* COMETS; *all illuſtrated by a curious* ORRERY, PLANETARIUM, *and* COMETARIUM.

1 THE Subject of this Section will be to explain the *true Syſtem of the World*, as it has been lately diſcovered and demonſtrated by the great Sir ISAAC NEWTON. By the *Syſtem of the World* is meant the Number, Diſpoſition, and Order of the Heavenly Bodies, both among themſelves, and with Reſpect to *one central Body*, about which the Motions of the Others are performed, and by whoſe Power and Influence they are governed and regulated.

2. The

2. The great Queſtion in all Ages has been, *whether the Earth or the Sun be the Center of the planetary Motions*; the Vulgar and illiterate Part of Mankind declare for the former; but all the Skilful and Learned not only aſſert the latter, but can eaſily prove and demonſtrate the ſame. Our *Senſes*, indeed, repreſent the *Earth* the largeſt of all Bodies, and at Reſt; and the Heavenly Bodies ſmall, and in Motion about it. But Reaſon, Learning, and Experience all teach us the contrary; and at the ſame time ſhew us, that nothing can be more fallacious than our common Senſations of Motion, Magnitude, and Diſtances of Bodies.

3. This vulgar Hypotheſis *of the Earth's being* the *Center of the Syſtem*, was taught in former Times by an *Egyptian* Philoſopher named *Ptolemy*, and from him it is called the *Ptolemaic Syſtem*. That which aſſerts the Sun to be the Center, is for that Reaſon called the *Solar Syſtem*; and becauſe it was firſt taught by the School of *Pythagoras*, and, when loſt for many Ages, was at laſt revived by *Copernicus*; and laſt of all demonſtrated and accounted for by Sir *Iſaac Newton*; it has alſo been called the *Pythagorean*, *Copernican*, and *Newtonian Syſtem of the World*.

4. The Indolence and Inattention of People are generally the Cauſe of their Ignorance; and they who will not make Uſe of their

Senſes to diſcover the *Figure of the Earth*, are not much to be depended upon for the *Rationale of a Planetary Syſtem*. But to leave Reflections, and come to Facts: I have contrived a Machine which I call a *Planetarium*, or Manual Orrery, that will at once repreſent both the *Ptolemaic* and *Newtonian Syſtem*, and fully and equally ſhew the *Falſity of the one*, and *the Truth of the other*.

5. In order to this, the *Ptolemaic Syſtem* is repreſented having the Earth in the Center immoveable, about which, when the Winch is turning, you ſee the ſeveral Heavenly Bodies move in the following Order, *viz.* *Mercury*, *Venus*, the *Sun*, *Mars*, *Jupiter*, and *Saturn*, juſt as ſhewn in the *Scheme*. Now in this Diſpoſition of the Planetary Bodies, ſeveral Things offer themſelves at firſt Sight quite oppoſite to the true and real *Phænomena* of the celeſtial Motions, ſome of which I ſhall here ſpecify, which will indubitably prove the Abſurdity and Falſity of this *Syſtem*.

Fig 1.

6. The firſt is, that by this Hypotheſis it is very evident that *Mercury* and *Venus* can never be ſeen from the Earth to go behind the Sun, becauſe both their Orbits are contained within that of the Sun; but in the Heavens we always ſee thoſe Planets go juſt as often behind the Sun as before it.

7. *Secondly*, according to this Scheme, the Planets *Mercury* and *Venus*, like all the Reſt, may

may be in *Conjunction* and *Oppoſition* to the Sun, or may be ſeen in any Poſition in the Heavens from the Sun. But this is quite contrary to Experience; no Man can ever ſee *Mercury* at more than about 21 Degrees from the Sun, and *Venus* never above 48, ſo far are they from being in Oppoſition or at the Diſtance of 180 Degrees from the Sun. *Venus* is the bright Evening Star, which every one knows was never ſeen in the *South*, much leſs in the *Eaſt*, at *Sun-Set*. And *Mercury* is ſo far from being ſeen in every Part of the Heavens, that he is very rarely ever ſeen by any-body.

8. *Thirdly*, in this *Vulgar Syſtem*, it is plain, ſince all the Planets are at an equal Diſtance in every Part of their Orbits from the Earth; they would neceſſarily appear always of the ſame Magnitude: But this is contrary to Experience, for we ſee the Planets, eſpecially *Mars*, perpetually altering their apparent Magnitudes, which proves they are not always at an equal Diſtance from us.

9. *Fourthly*, according to this Scheme, the Planets, as they are always equally diſtant from the Earth, muſt always appear to move with *equable* or *uniform Velocities*, or never faſter or ſlower at one Time than at another; which is directly contrary to what we obſerve in every Planet of the Syſtem.

10. *Fifthly*, If the common Hypotheſis were true, we ſhould ſee the Planets always move one Way, or in one Direction, *viz.* from *Weſt to Eaſt*, but, inſtead of that, we obſerve they ſometimes move *forwards*, ſometimes *backwards*, and ſometimes *not at all*, but are *ſtationary* in the Heavens for many Days together. Theſe Things, with many more which we muſt paſs by, plainly prove ſuch a Syſtem can have no Place in Nature, but is every Way repugnant to it, and therefore *falſe*.

11. But now if we reſtore the Sun to its rightful Place, the *Center of the Syſtem*; and the Earth to its proper Place among the Planets, and thereby repreſent the *Newtonian Syſtem* upon the ſame Machine, we ſhall ſee every Phænomenon of this Syſtem in the Planetarium agree with thoſe of the Heavenly Motions reſpectively; and not incumbered with the leaſt Difficulty or Abſurdity.

12. Thus, firſt of all, we obſerve, according to this Diſpoſition of the Planets about the Sun, that to a Spectator at the Earth the Planets *Mercury* and *Venus* will be ſeen to go both before and behind the Sun, or to have *two Conjunctions* with the Sun, but *no Oppoſition*; which are exactly their *Phænomena* in the Heavens.

13. *Secondly*, Let S be the Center of the Sun; and from the Earth ⊖ draw the right Line

Line ☉ G, ☉ H touching the Orbits of *Mercury* and *Venus* in the Points B and E; then if *Mercury* be at B, and *Venus* at E, they will there appear at the greateſt Diſtance from the Sun that is poſſible; and the Angle S ☉ B, being the greateſt Elongation of *Mercury*, is not above 21 Degrees; and that of *Venus* S ☉ E is but about 47. And this is exactly agreeable to what we obſerve of their Diſtances in the Heavens. Fig. 2.

14. *Thirdly*, In the *Newtonian Syſtem*, you obſerve all the Planets will have their Diſtances from the Earth perpetually varying; and conſequently their apparent Magnitudes will be always variable alſo. And this we obſerve every Day in the Heavens; thus when *Mars* at is M neareſt the Earth ☉, he appears near as large as *Jupiter*; but when at his greateſt Diſtance at R, you will ſcarcely diſcern him from a *fixed Star*, but by his red Aſpect. The Surfaces of all Bodies decreaſing as the Squares of the Diſtances increaſe. Now ☉ M is to ☉ R as 1 to 5; therefore the apparent Magnitude of *Mars* is 25 Times greater at M than R.

15. *Fourthly*, In this Scheme, as the Earth ☉ is not in the Center of the Planetary Motions, their *true Motions and Directions* cannot be ſeen by us, but only their *apparent ones*; and theſe are often contrary to the other. Thus, for Inſtance, while the Planet *Venus* is moving from F towards E, it

will appear to a Spectator at the Earth ☉ to move the ſame Way that it really does move, *viz. from Weſt to Eaſt*; but while it moves from E to D it will appear to go backwards, *from Eaſt to Weſt*. And thus in the Heavens, after *Venus* has gone forwards from the Sun to its greateſt Elongation, we always ſee it return again with a retrograde Motion to the Sun; and the ſame is obſerved of *Mercury*, and of all the other Planets.

16. *Fifthly*, In this Syſtem, it is evident the Planets muſt appear to move with *very unequal Velocities*; for ſince the Velocity is in itſelf uniform, and ſince it appears to deſcribe the ſame Arch in the Heavens in paſſing from F to E, as it does in paſſing from E to D, and E F is much larger than E D, therefore the apparent Velocity of its retrograde Motion thro' E D muſt be much greater than that of its direct Motion thro' F E. And thus the Motions of theſe Planets always appear to us in the Heavens.

17. *Sixthly*, At the Points E and B the Planets will appear to be *ſtationary*, or not to move at all for ſome Time, becauſe the Direction of their Motion in thoſe Points, for ſome little Diſtance on each Side, coincides with the right Line ☉ E and ☉ B, which touch the Orbits. And agreeable hereto, we find the Planets in the Heavens

always *ſtationary* at their greateſt Elongation from the Sun.

18. *Seventhly*, According to this Syſtem, if the Earth has a Motion about the Sun in its Orbit, then the Time between any two Conjunctions of the ſame Kind in *Venus* or *Mercury* muſt be longer than it would be if they were at Reſt; for in the latter Caſe, that Time would be equal to the *periodical Time* of the Planet's Revolution; but ſince the Earth moves as well as the Planet, that Time muſt be greater than the Planet's *Period*. For ſuppoſe, while that Planet performs its Period, the Earth moves on from ☉, then after *Venus* has returned to D, it muſt go on ſtill farther, ſuppoſe to L, before it comes again between the Sun and the Earth now at K. And this we always find to be the Caſe by Obſervation; which therefore plainly proves the *Motion of the Earth about the Sun*.

19. Since then this Syſtem, and this only, is every way conſiſtent with the Phænomena of the heavenly Motions, and by which they can be rationally accounted for; it follows, that this only can be the *true Syſtem of the World*. And indeed it is not only plainly demonſtrable by the foregoing Obſervations, but it is ſupported by the higheſt Reaſon. For ſince the Planets revolve in circular Orbits about a central Body, they muſt be conſtantly deflected from their right-

right-line Direction by a *centripetal Force* exerted upon them by this *central Body*. And as this *attracting Force* is well known to be proportional to the Quantity of Matter, it is evident, the Quantity of Matter in the central Body ought vaſtly to exceed the Quantity of Matter in any Body whoſe Motion it controuls and governs. And therefore the *Sun only*, whoſe Matter is many thouſand Times greater than that of all the Planets together, muſt neceſſarily be appointed for this Purpoſe; and not our *inconſiderable Globe of Earth*, which is *near a Million of Times leſs than the Sun*, and vaſtly leſs than *Jupiter or Saturn*.

20. Again it is extremely abſurd on another Account to ſuppoſe any other Body but the Sun ſhould be the *Center of the Syſtem*; for the Sun only is the Origin and Fountain of Light, and therefore that this might be equally diſpenſed to the whole Syſtem, and at all Times uniformly, to enlighten and animate the ſeveral habitable Globes, it was abſolutely neceſſary to aſſign the Sun a *central Situation*, ſince no other could poſſibly anſwer that End; for were he placed between *Venus* and *Mars*, as in the Ptolemaic Scheme, thoſe Planets would be ſcorched with Heat at his neareſt Approach, and be congealed to Stone at his greateſt Retreat. And ſuch would be the wretched State of the other Planets in a great Meaſure.

21. This

21. This *Syſtem*, therefore, as it is ſo noble a Work of Creation, and diſplays ſo much of the infinite Wiſdom and Power of God, deſerves a particular Deſcription. Accordingly I ſhall give a ſummary Account of the ſeveral Bodies of which it conſiſts, and the moſt remarkable Affections and Particulars relating to each.

22. The SUN is the central Body, and for that Purpoſe is the largeſt of all; ſo very great is his Bulk, that his Diameter is computed to be 822148 Miles, *viz.* 100 Times greater than that of our Earth, and therefore his Bulk a Million of Times greater than the Earth. The Surface of the Sun, when viewed thro' a Teleſcope, or in a dark Room, exhibits the Appearance of *dark Spots* of different Forms and variable in Number, but always uniform in their Motion over the Sun's Diſk, which plainly proves the Motion of the Sun about its Axis in 25 Days nearly. What theſe Spots may be, has not been yet diſcovered.

23. The firſt Planet in the Syſtem is MERCURY ☿, 2460 Miles in Diameter, and at the Diſtance of 32 Millions of Miles, revolves about the Sun in 88 Days; this Planet is the leaſt of all, and ſo near the Sun, that it is ſeldom viſible to us, and we know but very little of it. Fig. 3.

24. VENUS ♀ is the ſecond Planet, which at the Diſtance of 59 Million of Miles revolves about

about the Sun in the Space of 224 ¼ Days: it is leſs than the Earth, but how much, is not certain. This Planet has a Motion about its Axis in 23 Days, determined by the Appearance of a Spot on its Surface. Though it be a moſt ſplendid and glorious *Evening and Morning* Star, yet when in its greateſt Luſtre not half its Surface towards us is enlightened; but when viewed thro' a Teleſcope it appears horned like the Moon at 4 or 5 Days old.

25. The EARTH ⊕, or terraqueous Globe, on which we live, is the third Planet in order from the Sun, and it is at the Diſtance of between 81 and 82 Million * of Miles from it; its periodical Time, or Revolution about the Sun, is in 365 ¼ Days, and about its own Axis it revolves in 1 Day or 24 Hours, nearly. It is 7960 Miles in Diameter, and about 25000 in Circumference. It is the firſt Planet in the Heavens that is attended with a *Moon* or *Satellite*, of which more hereafter.

26. MARS ♂, the fourth Planet, at the Diſtance of 123 Millions, revolves about the Sun in 687 Days. It is leſs than either the Earth or *Venus*, being no more than about 4444 Miles in Diameter. It has always a red or

* The Diſtances of the Planets from the Sun, as here ſtated, are deduced from the Sun's Parallax being ſuppoſed 10 Seconds; whereas from the late Tranſit of Venus ſome have computed it to be 9½ Seconds, and others but 8½; and while there is ſuch Uncertainty, we ſhall let our Numbers remain without Alteration.

fiery

fiery Aſpect; has no Moon attending it, nor any Thing elſe remarkable about it.

27. But JUPITER ♃, the 5th Planet, is the moſt conſiderable of all, eſpecially in regard of his Bulk, as being no leſs than 81,000 Miles in Diameter; and therefore his Body or Globe *a thouſand Times greater than that of the Earth.* The Diſtance of *Jupiter* from the Sun is 424 Millions of Miles, and it revolves about the Sun in 4332 ½ Days or almoſt 12 Years. It is attended with 4 *Moons*; and with a good Teleſcope it appears to have ſome *cloudy Streaks* or *Belts* croſſing its Diſk, but what they are is not known.

28. The moſt remote Planet of the Syſtem is SATURN ♄, at no leſs than 777 Millions of Miles; it revolves about the Sun in 10759¼ Days, or in nearly 29 Years; and its Bulk is not very inconſiderable, being about 68,000 Miles in Diameter. It is attended with 5 *Moons*, and beſides them it has a very *large Ring* encompaſſing its Body at the Diſtance of 20,000 Miles, which is alſo the Breadth of the *Ring*; but what this wondrous Phænomenon is, has not as yet been diſcovered.

29. The MOON which belongs to our Earth is at the Diſtance of about 240,000 Miles; and revolves in the Space of 27 Days 7 Hours and 43 Minutes. This is called the *periodical Month*; but the Time which paſſes between *two new Moons* is 29

D. 12 H. 44′, and is called a *Synodical Month*; for the Reaſon of which Difference ſee *Art.* 18. The Diameter of the Moon is about 2175 Miles; the Moon is therefore about 50 Times leſs than the Earth.

30. The Reaſon why the *Moon always ſhews the ſame Face to the Earth*, is, becauſe it turns round its own Axis in the ſame Time that it revolves about the Earth. And the Reaſon of its doing this, is, becauſe the *Earth's attracting Power* governs not only the *Motion*, but alſo the *Poſition* of the Moon; for as it acts always uniformly, ſo whatever Part of the Moon did at firſt turn towards the Earth, it muſt always keep towards it of Courſe; and the Manner how this is done, I ſhew by a new Contrivance in the *Planetarium*.

31. The *Motion* of the Moon about the Earth is extremely irregular, which I have elſewhere accounted for. The *Phaſes* of the Moon are all exhibited, and the Reaſon of them clearly ſeen while the Moon revolves about the Earth in the *Orrery*. The Surface of the Moon appears through the Teleſcope very uneven, being in ſome Parts ſo vaſtly mountainous, that ſome of the Hills are at leaſt 9 Miles high, and the Vales, or rather Pits, ſo large, as to be 2 or 300 Miles over, and as many deep. There appears nothing like an *Atmoſphere* about the Moon, nor *Clouds*, nor conſe-

quently have they any kind of *Meteors*; and therefore the *Inhabitants of the Moon* muſt be quite of a different Nature from *us*.

32. As to Eclipſes, they happen in the Sun only, by the *Moon's intervening between it and the Earth*, by which means the Shadow of the Moon falls upon the Earth when the Latitude and Diſtance of the Moon do not prevent it, by elevating the Moon above, or depreſſing it below the Earth, in or near the Time when it is new; for then only can an Eclipſe of the Sun happen. The Shadow of the Moon is of two Sorts, *viz. Total or Partial*; whoever lives on that Part of the Earth's Surface, where the total or dark Shadow falls, ſees the Sun *totally eclipſed*; thoſe in the *partial Shadow* or *Penumbra*, ſee the Sun eclipſed in Part only: And there is a third Caſe, in which the Shadow does not reach the Earth, and produces an *annular Eclipſe* of the Sun.

33. On the other Hand, an Eclipſe of the Moon can only happen when *the Earth is interpoſed between the Sun and it*; for then, if the Latitude of the Moon does not prevent, the Shadow of the Earth may fall on the Moon, and thereby cauſe either a *partial* or *total Eclipſe*; and conſequently theſe *lunar Eclipſes* can happen only at or near the Time of the *full Moon*. And indeed, if the Plane of the Moon's Orbit was coincident with the Plane of the Earth's Orbit, there would be always a *ſolar*

lar Eclipſe at the *new Moon*, and a *lunar Eclipſe* at the *full*. The Manner how all this Affair of Eclipſes is occaſioned, will appear very plainly in the Machine.

34. The next Planet to our Earth which we find attended with Moons, is *Jupiter*; there have been 4 diſcovered, and may be eaſily ſeen through the Teleſcope in a clear Night; their Diſtances from *Jupiter*, eſtimated in Semidiameters of his Body, and the Times in which they revolve, are as follow.

Satellite	Semid.	Days	H.	′.
1 - -	5 $\frac{6}{10}$ - -	1 :	18 :	27
2 - -	9 - -	3 :	13 :	13
3 - -	14 $\frac{3}{10}$ - -	7 :	3 :	42
4 - -	25 $\frac{3}{10}$ - -	16 :	16 :	32

35. In *Saturn*, beſides his Ring, we diſcover 5 Moons or Satellites revolving about him, whoſe Diſtances, eſtimated in Semidiameters of his Ring, and the Times of their Revolutions, are as follow.

Satellite	Semid.	Days	H.	′.
1 - -	2 nearly	1 :	21 :	18
2 - -	2 $\frac{4}{10}$ - -	2 :	17 :	41
3 - -	3 $\frac{2}{3}$ - -	4 :	12 :	25
4 - -	8 - -	15 :	22 :	41
5 - -	23 $\frac{3}{10}$ - -	79 :	7 :	16

36. Theſe Moons of *Saturn* being ſo very remote from us, cannot be ſeen but by

by a very good Teleſcope, though the Ring may; the Moons of *Jupiter* appear only as ſmall Stars, and nearly in a right Line, becauſe the Planes of their Orbits are nearly the ſame, and parallel to the Plane of the Earth's Orbit. As theſe Moons may be ſometimes in the Shadow of their Primaries, ſometimes behind and before them, and ſometimes one may intercept the View of another, it muſt happen that we can very rarely ſee them all together.

37. Such are the primary and ſecundary Planets which compoſe our Syſtem. Of the Comets I ſhall ſpeak by-and-by. Of all the primary Planets we know but little, excepting the *Earth* on which we live. And here we ſhall find ſeveral capital *Phænomena* which command our Attention, and can only be explained (ſo as to be clearly and rationally underſtood) by the *Orrery* and *Planetarium*; in which Machines *four Motions* of the Earth will be exhibited, *viz.* 1. The *annual Motion* about the Sun. 2. The *diurnal Motion* about its own Axis. 3. The Motion about the common Center of Gravity between it and the Moon. 4. The Motion about the *Axis of the Ecliptic*. Of which in Order.

38. As by the *Day* we mean nothing but the *Preſence of the Sun*, and by *Night*, his *Abſence*; ſo the general *Cauſe* of Day and

Night is nothing more than the Sun's ſhining on the Globe of Earth, by which Means one Hemiſphere is enlightened, and the other dark; and as the Earth revolves upon its Axis once in 24 Hours, it muſt cauſe every Part on the Surface to paſs thro' both the enlightened and dark Hemiſphere in that Time, and ſo muſt neceſſarily produce an *Alternation of Day and Night* to every Place. And if the Circle, which bounds the light and dark Hemiſphere, paſs through the Poles of the Earth, it muſt occaſion the Day and Night to be of an equal Length.

39. If the Axis of the Earth were always perpendicular to the Plane of its annual Motion, then would the Sun appear always in the Equator, and therefore equally diſtant from all Parts of the Earth on each Side under equal Latitudes; and conſequently there muſt be in every Latitude one and the ſame Seaſon of the Year perpetually.

40. But if the Earth's Axis be inclined to the Plane of its Motion, and be kept always in a Poſition parallel to itſelf, while it revolves about the Sun, then in this Caſe one End of the Axis will, in one Poſition, be inclined to the Sun, and the other will be turned from it; the former will be included in the enlightened Hemiſphere, the latter in the dark one. And the Earth revolving about its Axis, will occaſion every Part

Part about the Pole in the enlightened Hemiſphere to deſcribe a larger Part of its Circle in the light, than in the dark Hemiſphere; and conſequently will *make the Day longer than the Night* in all thoſe Places. And juſt the contrary will happen with reſpect to the Parts about the other Pole, or Extremity of the Earth's Axis.

41. To illuſtrate this Matter, let S be the Sun illuminating the Earth in three different Poſitions in its Orbit, denoted by 1, 2, 3. Let C B be perpendicular to the Plane of the Earth's Motion, and let the Axis of the Earth N S be inclined thereto in an Angle N A C = 23° 29′, and be always in a parallel Poſition. Then it is evident, that the North Pole N, and all about it from N to C, or 23° 29′, will be in the enlightened Hemiſphere C E B in the 3d Poſition. And the South Pole S, and the Parts about it, will be in the dark Hemiſphere; juſt the contrary of all which you obſerve in the 1ſt Poſition. But in the 2d Poſition, as the Circle which bounds the Light and dark Hemiſpheres, paſſes thro' both the Poles N, S, it will cauſe that the Parts about each of them will be equally enlightened. Fig. 4.

42. Hence every Part in all the Northern Hemiſphere E N Q, being turned to the Sun in the 3d Poſition, will have the Days longer than the Nights; thus ſuppoſe D H

be the Semicircle, which the City of *London* deſcribes by the Earth's diurnal Rotation between Noon at D, and Midnight at H, it is plain the Length of the Day repreſented by D G is much longer than that of the Night G H; and it is as evident that the Night will be longer than the Day to all Places in the oppoſite or Southern Hemiſphere E S Q in this Poſition of the Earth.

43. Again, the Earth in the 1ſt Poſition will have all the Northern Hemiſphere E N Q turned from the Sun; and the North Pole N, and all about it to C, for 23° : 29′, wholly in the Dark; and every Place, as *London* in the Parallel D H, will have the Night D G much longer than the Day G H; and the ſame Arch that meaſures the Length of Day and Night in one Poſition, meaſures the Night and Day in the other. The Southern Hemiſphere E S Q is turned to the Sun, and every Place therein has the Day longer than the Night.

44. In the 2d Poſition the Circle bounding Light and Darkneſs paſſes through both the Poles, and muſt thereby neceſſarily make *Day and Night equal* in every Place on the Globe. This can happen but twice in the Year, and thoſe two Days are called the *Equinoxes*, *viz.* the 21ſt of *March*, and 23d of *September*. Thus all the Variety that happens with reſpect to Day and

Night

Night, will be clearly ſeen, and moſt eaſily apprehended from the Motions of the Earth in the Orrery.

45. To the ſame Cauſe alſo, *viz.* the oblique Poſition of the Earth's Axis N S to the Axis of the Ecliptic C B, we owe all the agreeable Alternations and Viciſſitudes of the Seaſons. For in the 3d Poſition as all the Northern Hemiſphere is turned to the Sun, we may obſerve; 1. That the Sun-Beams fall more directly upon it; and therefore ſtrike with a greater Force. 2. A greater Number of Rays will fall on a given Space; and therefore the Heat will be the greater. 3. The Rays in this Caſe paſs thro' a leſs Quantity of the Atmoſphere, and ſo their Action will be more intenſe. 4. The Sun's Preſence exceeds his Abſence; and therefore the Light and Heat of the Sun will on all theſe Accounts make this the moſt *lightſome* and hotteſt Seaſon of the Year, and what we call SUMMER.

46. On the other Hand, in the lower Part of the Earth, all about the Southern Pole to the Antarctic Circle B, is in the dark Hemiſphere; the Sun-Beams are very weak, and of ſhort Continuance, in the Southern Hemiſphere E S Q, and there make the cold and dreary Seaſon we call WINTER.

47. In the firſt Poſition, every Thing is juſt the reverſe; in all the Northern Latitude from Q to N it is *Winter*; and in all

the Southern from Q to S, it is *Summer*, for the Reaſons above aſſigned. And ſince in the 2d Poſition the Sun enlightens the Globe from Pole to Pole exactly, the Heat muſt neceſſarily be there in a mean Degree, and make the Middle of the *Seaſons* we call SPRING, and AUTUMN. All which is very clearly explained and illuſtrated in the *Orrery* and *Planetarium*.

48. Beſides the annual and diurnal Motions of the Earth, there is another, which is a conical Motion of the Earth's Axis, by which the Poles of the Earth revolve about the Poles of the Ecliptic in a *retrograde* Manner, and ſo very ſlowly as to amount to no more than *one Degree* in 72 Years, or one Revolution in near 2600 Years. And therefore in the Space of a few Years it is altogether imperceptible.

49. Yet as in a long Courſe of Time it becomes very ſenſible, and induces very conſiderable and momentous Alterations and Changes in the preſent (and ſeemingly conſtant) State of Nature; I ſhall contrive by a *Diagram* to repreſent it very plainly, tho' it cannot be ſo completely conceived as by ſeeing it actually performed in the *Planetarium*. Let E N Q S be the Earth; Fig. 5. E Q the Equator; N S the Axis of the Earth making an Angle N C P of 23 ½ with the Axis P L of the Ecliptic; T R is the Tropic of Cancer, B D that of Capri-

corn;

corn; and P *r*, *b* L, the two polar Circles in the preſent Poſition of the Earth's Axis.

50. Now the Earth's Axis N S is always in Motion upon the Center C, moving backwards in ſuch Manner as to deſcribe the Surface of a *Cone* N C *n*, in the doing of which, it will by its Direction continued to the Stars, deſcribe among them the Circle W X Y Z, whoſe Diameter is 47 Degrees of a great Circle. In Conſequence of this, the Star W, which is at preſent nearly over the North Pole N, will be in Time deſerted by the Pole N, which by this conical Motion will be carried backwards, and after about 6500 Years it will be directed to a Star X, which is now in the Eaſt, and this will then be our North Star.

51. After this in 6500 Years more, the Axis of the Earth will get into the Situation *n s*, and point to the Heavens at Y, which will then be the *North Pole*, 47 Degrees from the preſent North Pole at W; and 8 $\frac{1}{2}$ Degrees South of the Zenith of *London*, whoſe Parallel or Path is G H. After this, it will recede in the ſame Time to Z, in the preſent weſtern Part of the Heavens, and nearly there it was at the Creation, or about 6000 Years ago; ſince which Time it has crept backward to W, where it now is.

52. By this Motion of the Earth, as each Part of its Surface is ſlowly turned about backward from Eaſt to Weſt, the Stars will

all ſeem to move forwards from Weſt to Eaſt in the ſame Time; and hence it is that they are conſtantly changing their *Longitude* in the *Ecliptic*, and *Declination* from the *Equator*. And thus the Conſtellation which was formerly in *Aries* is now in *Taurus*; that of *Taurus* is now in *Gemini*; and ſo of the Reſt.

53. Hence alſo it is, that as the equinoctial and ſolſtitial Points are carried backwards, the Sun will arrive to them each Year ſooner than if they were at Reſt, and conſequently make what we call the *Preceſſion of the Equinoxes*; becauſe the Time of the *Equinoxes* each Year will *precede* the Time in which it happened the Year before.

54. Hence all the Seaſons of the Year will have a retrograde Motion thro' all the Months of the Calendar; and it is eaſy to ſee from the Figure, that there is in the Space of. 13000 Years ſo different a Poſition of the Circles of the Sphere with reſpect to the Ecliptic, that in the preſent Poſition the *Tropic of Cancer* T R touches the *Tropic of Capricorn b d* at the End of that Period; whence it appears the Sun is now in that Part of the Ecliptic on the longeſt Day, where it will then be on the ſhorteſt, and *vice verſa*.

55.

55. The Cauſe of this Motion of the Earth, Sir *Iſaac Newton* has ſhewn to ariſe from the Figure of the Earth not being *ſpherical* or *truly globular*, but of an *oblate Form*, having the Diameter E Q of the Equator longer than the Axis N S by about 80 or 90 Miles. Alſo that this was owing to the *centrifugal Force* (ariſing from the diurnal Rotation) being much greater in Parts near the Equator than in thoſe towards the Poles.

56. We come now to contemplate the Motion of Comets, which make a very wonderful Part of the *Solar Syſtem*. Theſe are a Sort of Planets, quite different from thoſe we have been ſpeaking of, as they are capable of ſuſtaining the *greateſt Alternations* of *Heat and Cold*, and revolving about the Sun in very *eccentric Orbits*. They appear ſurrounded with a large and denſe Atmoſphere, which when near the Sun becomes greatly heated, raiſed, and expanded into a ſurpriſing large and fiery Vapour, or Tail, which makes it appear a *blazing Star*.

57. With reſpect to the Cauſe and Manner of a Comet's Motion, we are to obſerve that tho' the Form of its Orbit be very elliptical, yet the Motion in that Ellipſis is the Reſult of two Forces acting upon the

Comet (as well as in the Caſe of a Planet) *viz.* One a *projectile Force*, which would alone carry it from the Sun in a Right-line; and a *centripetal* Force (or Gravity) by which alone it would be carried directly to the Sun. Now in the Caſe of a Comet, both theſe are ſo compounded together as to make it deſcribe an Orbit more or leſs *elliptical* about the Sun, or Center of Force.

58. But to be more particular, let A F P C be the elliptic Orbit of the Comet C; C T its Tail, A its *Aphelion* or greateſt Diſtance, and P its *Perihelion*, or leaſt Diſtance from the Sun S. Now the Power of Gravity upon the Comet every where decreaſes as the Squares of the Diſtances increaſe. So that if S A be 10 times S P, the Gravity at P will be 100 times greater than at A; and therefore the Velocity of the Comet at P, and in all Parts about the Sun, is vaſtly greater than in the remote Parts of the Orbit, and at A, where it moves ſloweſt of all.

Fig. 6.

59. If we ſuppoſe the Comet deſcribes the Arches P B, B D, D E, in the ſame or equal Times, then will the Areas P S B, B S D, D S E, be equal to each other; which is the conſtant Law of all the planetary Motions. The Reaſon why the Comet does not go quite away from the Sun at A is be-

cauſ

cauſe the Force by which it goes off from the Sun decreaſes, in receding from the Sun in a much greater Proportion than Gravity, by which it is therefore made to turn round at A, and again to approach the Sun. And at P, the ſame Force prevails over the Force of Gravity, and prevents its falling into the Sun, by whirling it ſwiftly round in that Part.

60. There have been a great Number of Comets obſerved from time to time; but tho' it be ſufficiently diſcovered that they move about the Sun in the Manner above explained, yet ſcarcely any of them have been obſerved to return often; and only one ſo often as to have the periodical Time of Revolution and Form of its Orbit determined with Certainty. This Comet has appeared ſix ſeveral Times, at the Interval of $75\frac{1}{2}$ Years; and the laſt time it appeared was *An. Dom.* 1757 & 58, exactly agreeable to the Prediction of Dr. HALLEY. All theſe Particulars of a Comet's Motion are repreſented to the Eye by the *Cometarium*, and exemplified at large inthe Comet laſt-mentioned. Alſo by a new Conſtruction and Elevation of the Plane of this Comet's Orbit, and in a large Copper-plate, intituled, 'The WONDERS of the *Cometary* WORLD diſplay'd, *&c.*' by which it will appear how enormouſly large their Tails are; and by what a ſignal Providence we are conſtantly

ſtantly preſerved from the deſtructive Shock of thoſe flaming Vapours, when they tranſit the Earth's Orbit with a ſtupendous Velocity. For more on this Subject, ſee my NEW THEORY of COMETS demonſtrated, and exemplified by Calculations.

MUSEUM PATAVINUM

Plate IV

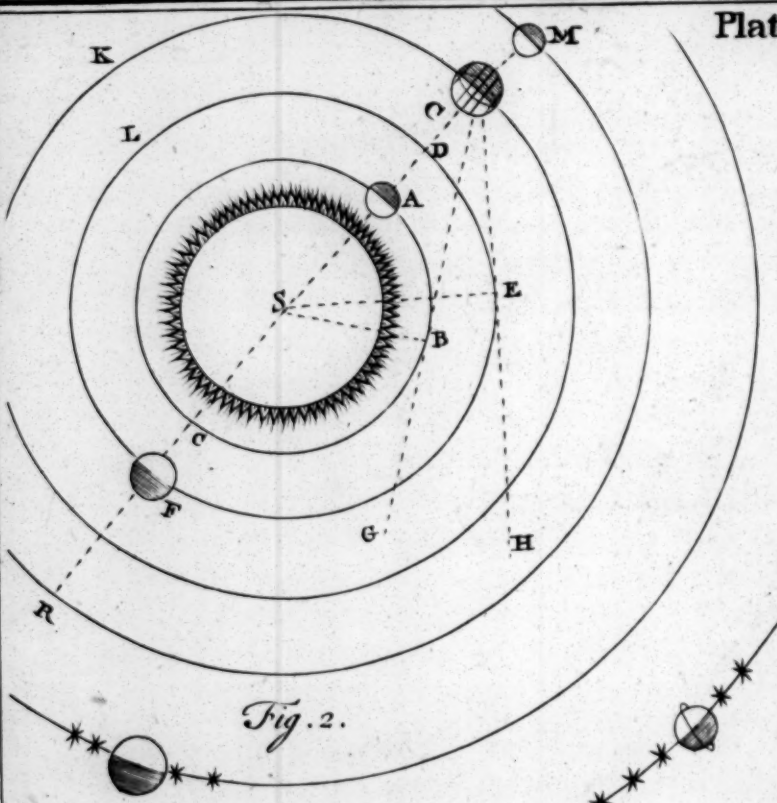


Fig. 2.

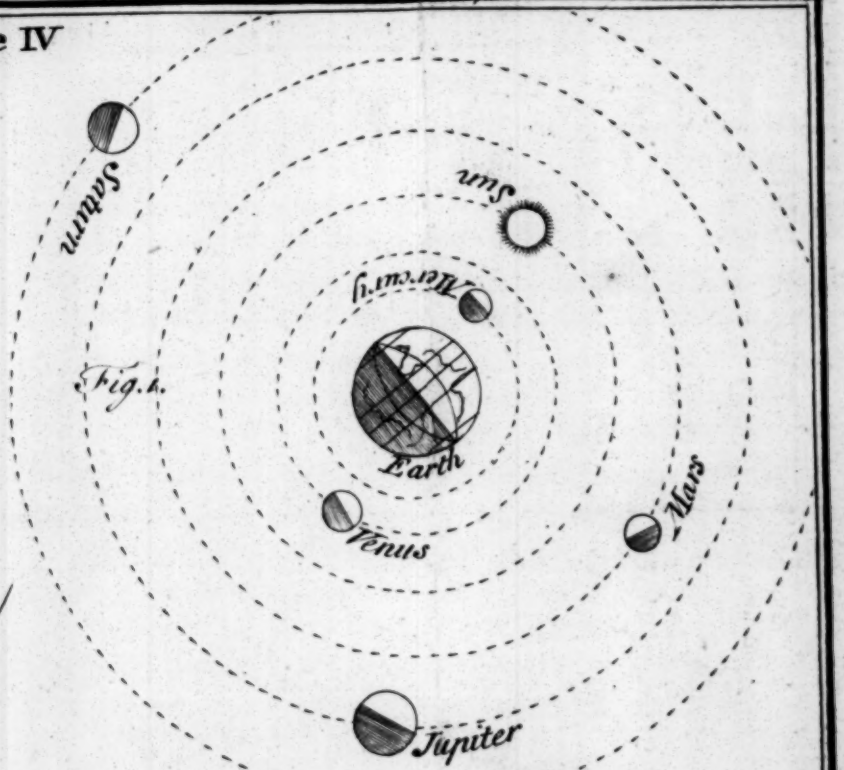


Fig. 1.

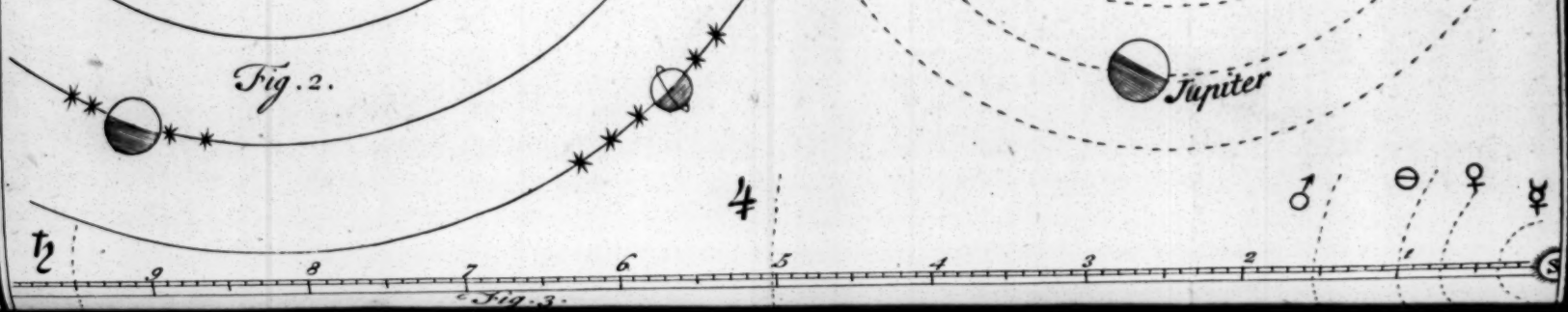


Fig. 3.

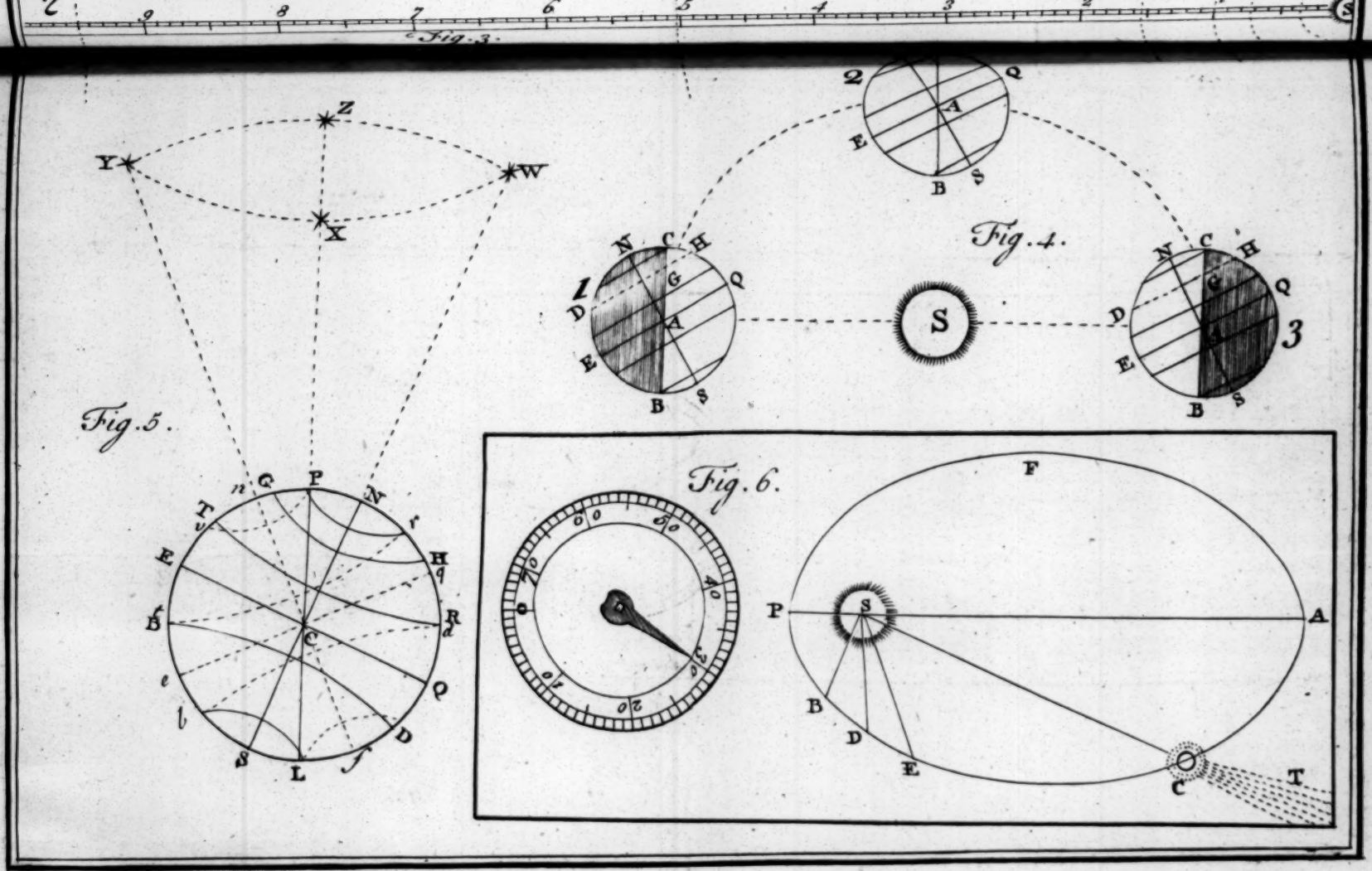

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Fig. 5.
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Fig. 4.
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Fig. 6.
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SECTION V.

The Nature of FLUIDITY, *and* Fluid Bodies *explained*; *the* Hydroſtatic Paradox; *the Nature of* Sinking *and* Swimming; *the* Specific Gravities *of Bodies by the* HYDROSTATIC BALLANCE; *the Uſe of the* HYDROMETER; *of* AQUEDUCTS *and* FOUNTAINS; *the Theory of* Pump-work; *ſeveral curious Sorts of* PUMPS; *the Theory of the Tides*; *Newſham's* WATER-ENGINE, *&c.*

1. THIS Section is intended to explain and illuſtrate that Part of Natural Philoſophy which is called HYDROSTATICS, and which treats of the Nature and Action of *Fluid Bodies*, and the Conſtruction and Rationale of ſuch Inſtruments and Machines as depend upon their peculiar Properties. The Definition of a Fluid is —*A Body whoſe Parts move freely among themſelves, and therefore yield to the leaſt Force that is impreſſed upon them, more on one Part than another*; for if the Force be uniformly exerted over all the Surface, no Particle can poſſibly move.

2. The

2. The Reaſon of this Definition is derived from the Nature of the Thing; for it has been ſhewn in the Firſt Section, that the Power of Coheſion unites and binds the Parts of Matter together with various Degrees of Force, in proportion as they touch by a greater or leſs Quantity of Surface; and conſequently thoſe which touch by the leaſt Number of Points, muſt be moſt free to move among themſelves by any Force impreſſed, and therefore muſt conſtitute a fluid Body in the moſt perfect Degree.

3. In order that the Particles of Matter may touch by the leaſt Quantity of Surface poſſible, *their Figure muſt be perfectly round and ſpherical.* Hence it follows that ſince even in ſpherical Particles there will be a ſmall Degree of Contact, and, conſequently, of Coheſion or Tenacity, there is no Body in Nature *abſolutely fluid*; unleſs it can be ſhewn, that the Particles of ſome fluid Bodies do not actually touch each other; and indeed there are not wanting Experiments which favour ſuch a Concluſion.

4. However that Matter may be, we have Bodies ſo far fluid as to acquire by that Means ſome very peculiar, wonderful, and uſeful Properties, and the Manner of acting quite different from *ſolid Bodies.* Indeed both ſolid and fluid Bodies act only by Preſſure ariſing from the Gravity of their Parts; but then in Solids, this Action or Preſſure

is only in *one Direction, viz. perpendicularly downwards,* and *in proportion to the Quantity of Matter.* Whereas Fluids preſs not in one only, but in *every Direction, upwards, downwards,* and *ſideways,* equally; and that with a *Force not proportional to the Matter, but to the Height of the Fluid.*

5. The natural Reaſon of this is evident; for ſince every Particle is quite free to move, and all preſs each other on every Side and in all Directions, it is plain, if any one Particle or more were preſſed on one Part more than another, they would inſtantly move, and continue their Motion till ſuch Time as they acquired a Situation where the Preſſure is on every Side equal; and in that Caſe only, the Body of the Fluid could attain its *natural State of Reſt.*

6. That the Preſſure of Fluids is every Way and in all Directions equal, may and will be ſhewn by divers Experiments in the Sequel of this Section. There is no Need of an Experiment to prove the Preſſure of Fluids downwards. But their *Preſſure upwards* is a Matter not ſo well known or eaſy to be conceived, and therefore I ſhall make it plain and evident by the following Experiment. A B C is a tall Tube filled with Water near the Top, into which a ſmall Tube D C is immerſed with its open End C downwards, the other End D being hermetically ſealed. Fig. 1.

7. In

7. In the leſſer Tube, the Water is ſeen to riſe to the Height C E, which directly demonſtrates a perpendicular Preſſure of the Water upwards in the Tube; becauſe as the Tube is full of Air when immerſed, and the Air is a ſpringy Body, it would by virtue of its Spring reſiſt the Water and prevent its Entrance into the Tube, were it not that the Water preſſes againſt the Air with a greater Force, and by that means cauſes the Air to retreat from the Orifice up into the Tube ſo far, till its Denſity makes its Spring equal to the Force of Preſſure in the Water, and then it can riſe no higher.

8. That this Preſſure upwards at the Point C is equal to the Preſſure downwards at the ſame Place, will be ſhewn farther on. And ſince there is known to be a Preſſure upwards and downwards equally in every Part, and alſo that the Force with which fluid Particles preſs, or are preſſed, is on every Part equally the ſame (*Art.* 4. 5.) it follows, that there is a Preſſure in Fluids *laterally* or ſideways, and every Way *equal to the Gravity*, and proportional to the *Height of the Fluid*.

9. But what is ſtill more wonderful, and deſervedly called the *Hydroſtatic Paradox*, is, *that this Preſſure of Fluids is proportional to the Height of the Fluid only, without any Regard to the Quantity thereof*; or, in other Words, while the Baſe or Bottom on which the

the Fluid preſſes remains the ſame, if the Height of the Fluid be increaſed, the Preſſure on the Bottom ſhall be increaſed in the ſame Proportion, though the Quantity of the Fluid be the ſame all the while. And this is clearly evinced by the following Experiment.

10. Let A B C D be a hollow Cylinder of Braſs, Glaſs, *&c.* within which a Bladder containing Water is freely ſuſpended by a Braſs Top at A B, and having a Braſs Bottom *a b* G; in the Middle of which at G is ſcrewed a long Braſs Wire G H hanging to the Hook of a Steel-Yard at H; about this Wire is ſcrewed the tall Glaſs Tube E F in the Center of the Top A B: When this Wire is diſengaged from the Steel-Yard, the Bottom of the Bladder is in its loweſt Situation *c d*, and the Water is juſt ſeen in the Tube at E. Suppoſe now the whole Quantity of Water A *c d* B were a Pint, or one Pound. Fig. 2.

11. Then upon hanging the Wire G H on to one Part of the Steel-Yard, and a Pound Weight on to the other, it is evident that Weight, by means of the Wire, will act upon the Braſs Bottom *a b* in a Direction quite contrary to that of the Preſſure of the Water; and conſequently, where-ever the Bottom *a b* is at Reſt, there will be an Equilibrium or Equality of Force between the Action of the Weight and the Gravity of the

Water upon it; and ſo the Preſſure of the Water will be always expreſſed in *Pound Weights*. Thus, ſuppoſe the Pound Weight were placed on the firſt Diviſion of the Steel-Yard, as the Water is alſo one Pound by Suppoſition, it is plain the Bottom will retain its Situation *c d*, and the Water will not be ſenſibly moved upwards. But upon moving the Pound Weight to the ſecond Diviſion of the Steel-Yard, it will act upon the Bottom with the Force of two Pound; and therefore ſince the Water acts upon it with the Force of but one Pound, it follows that the Bottom will be drawn up, and the Water will riſe in the Tube to a Height which is ſuch, that a Cylinder of Water of that Height, and of the ſame Baſe *a b*, will weigh juſt one Pound. The ſame Quantity of Water, therefore, now preſſes the Bottom with double the Force as at firſt.

12. If the Pound Weight be removed ſucceſſively to the 3d, 4th, 5th, 6th, *&c.* Diviſions of the Steel-Yard, the Bottom will be drawn upwards with Forces which will be as 3, 4, 5, 6, *&c.* Pound; and therefore the Water will riſe in the Tube to the Heights E 2, E 3, E 4, E 5, E 6, *&c.* whence it appears, that the Force or Preſſure of Fluids is every-where proportionable to the Altitude of the Fluid, and to that alone. Which was to be proved.

13.

13. The natural Reaſon of this wonderful Phænomenon of Fluids is this, *viz.* That ſince the Preſſure of Fluids upwards at the ſame Depth below the Surface is the ſame as downwards (*Art.* 6, 7.) the Water will every-where preſs upwards againſt the fixed Top of the Veſſel A B, and upon the Whole with a Force equal to the Weight of a Cylinder of Water of the ſame Height of that in the Tube, and Baſe the ſame as A B, as is evident by the Experiment. Now ſince the Top A B is fixed, it will re-act upon the Water with juſt the ſame Force as the Water acts upon it, and ſo will, by this *Re-action*, ſupply the Want of Weight of ſuch a Cylinder of Water as above-mentioned. This Force of Re-action, then, joined with the Weight of the Water below A B, muſt neceſſarily be the ſame upon the moveable Bottom *a b*, as the Weight of a Cylinder of Water on the ſame Baſe and the Height of that in the Tube. *This Force of Re-action* will be fully explained in the next Section.

14. By the ſame Principle in Fluids, it is, *That a heavy Body immerſed in them always loſes juſt ſo much of its Weight as is equal to the Weight of an equal Bulk of the Fluid.* For no Body can deſcend in a Fluid without raiſing an equal Bulk of that Fluid; and that equal Bulk of the Fluid will reſiſt or re-act againſt the deſcending Body *with all its Force of Gravity*; and ſince *Action and Re-*

action are equal (Sect. VI.) it follows, that juſt ſo much Gravity muſt be deducted from the Body immerſed, and it will deſcend with the Remainder, or reſidual Gravity.

15. To ſhew this by Experiment, Fig. 3. we have a ſolid Cylinder A B of Braſs, which exactly fits the hollow cylindric Bucket C D, and ſuſpended from the Bottom of it by the String E F; this Bucket and Solid are counterpoiſed very nicely in the Air by a Weight G on the Balance H I. While they are thus in Equilibrio, the Solid is immerſed in the Water K L, upon which the Equilibrium is immediately deſtroyed, the Weight G preponderating very conſiderably. If now, Water be poured into the Bucket C D till it be full, the Equilibrium is reſtored again; and that by the *Addition of the Weight of an equal Bulk of Water*, which fully proves this moſt uſeful Propoſition of Hydroſtatics.

16. Hence it appears, that the true and abſolute Weight of Bodies cannot be immediately known by the Balance, unleſs they could be weighed *in vacuo*; ſince when they are weighed in any *Medium*, as Air, Water, *&c.* we have only the Difference of the Weight of equal Bulks of the Body and the Medium. Hence we derive the Idea or Definition of *Specific Gravity*, which is a relative Term, and implies no more *than*

the

the Gravity of one Body compared with that of another under equal Bulks. Thus if a Cubic Inch of Glaſs be three times heavier than a Cubic Inch of Water, its ſpecific Gravity is ſaid to be three times as great as that of Water.

17. To find how much heavier any Body is than Water, and conſequently to determine the various ſpecific Gravity of Bodies in general, we have the Invention of the HYDROSTATIC BALANCE, the Reaſon of which will be quite evident from the foregoing Experiment (*Art.* 15.) and the Uſe of it extremely eaſy in the *new Method* I have contrived for that Purpoſe, and which I ſhall next exhibit and exemplify.

18. Let I K repreſent this Balance, and its two Scales H, F; to the Scale F, I fix a *Horſe-Hair* F G, with a Loop at the lower End G, by which a Body, as A B, may be very readily ſuſpended. Suppoſe then A B were a Piece of *Braſs*, whoſe ſpecific Gravity is required to be found; proceed thus; Suſpend it in the Horſe-hair, and find its Weight in Air by Grain Weights put into the oppoſite Scale H, till there is a nice Equilibrium, then lifting the Body A B up, place under it a Glaſs of Water C D, in which let the Solid ſink, and it will become lighter, and the Scale H will preponderate (*Art.* 14.) then let Grain Weights be put into the other Scale F till the Equilibrium be re- Fig. 4.

ſtored; theſe will expreſs the Weight of a Bulk of Water equal to AB (*Art.* 15.). Now the Weights in H are to the Weights in F as the Weight of Braſs to the Weight of Water under equal Bulks; and therefore *the ſpecific Gravity of Braſs is known.*

19. And it will always be found that the Weights in the Scale H will be to thoſe in F as 8 to 1 nearly; and if the Solid AB were *Gold*, thoſe Weights would be as $17\frac{1}{2}$ to 1; in Silver they are as about 10 to 1; in Lead as $11\frac{1}{3}$ to 1; and ſo a Table may be compoſed, exhibiting the ſpecific Gravities of as many Kinds of Solids as you pleaſe.

20. And it is ſtill more eaſy to find the ſpecific Gravities of Fluids; for in this Caſe nothing more is neceſſary than firſt to equipoiſe any Solid AB in the Air, and then immerſe it ſucceſſively in as many different Sorts of Fluids as you will; and the Number of Grains put into the Scale F each time to reſtore the Equipoiſe, will repreſent the ſpecific Gravities of thoſe Fluids reſpectively, becauſe they expreſs their Weights ſeverally under equal Bulks.

21. In this Way alſo one might find the ſpecific Gravity of Quickſilver by immerſing a Piece of Gold in it (for nothing but Gold is heavy enough to ſink into it); but for Variety's Sake, I ſhall ſhew another Way of doing it. Let AB be a tall Glaſs Tube cloſe at the Bottom, in which pour a little Mercury

cury to the Height D C. In this let a ſmall Tube G B be placed, open at both Ends, and upon the Mercury pour Water till its Height C F be equal to 14 Inches; then will the Mercury be raiſed in the Tube B G to the Height C E equal to one Inch. Now ſince the Preſſure or Gravity of Fluids is proportional to their Heights only (*Art.* 9.) and ſince there is an Equilibrium between one Inch of Mercury and 14 Inches of Water, it is plain *that Mercury is* 14 *times more denſe, and therefore* 14 *times heavier than Water.*

22. The Uſe of this Experiment is very extenſive, as we ſhall ſee farther on, and perhaps there is nothing that will afford a clearer Idea of the Reaſon of the Tides, or Flowing and Ebbing of the Sea. For ſuppoſing the Earth I F G H were wholly covered over with Water; and if this Water were affected by the Earth's Attraction only, it would be every-where of a ſpherical Figure A B C D (by what was ſhewn in Sect. I. 8.) be- Fig. 6. cauſe every Particle being equally attracted there muſt be an equal and uniform Denſity and Gravity, and conſequently an equal Height of the Water throughout the Whole.

23. But ſuppoſing the Moon at M attracts the Waters at the ſame Time, this will be in a contrary Direction to that of the Earth in all the Hemiſphere A B C next the Moon, and thereby the Gravity of the Waters will be diminiſhed, and moſt of all thoſe Parts

near the Moon. As the Waters then are thus made lighter about D than at A or C, there will be required a greater Altitude in thoſe at D to maintain the Equilibrium with the heavier Water at A and C. The Waters therefore at D will riſe from D to *d*; and proportionally every-where towards A and C.

24. In all the oppoſite Hemiſphere A B C the Attraction of the Moon conſpires with that of the Earth, and the Gravity of the Waters will always be proportional to the Sum of theſe Attractions, which will be leaſt of all at B, as being moſt remote from the Moon; the Waters, therefore, at B will be lighteſt of all, and conſequently muſt riſe to a greater Height G *b* than any-where elſe towards A and C.

25. As the Waters riſe about the Parts D and B, they muſt neceſſarily ſubſide below the Circle in the Parts A and C to the leſſer Heights F *a*, H *c*. As theſe Points A, B, C, D, are 90 Degrees diſtant, they muſt come to the Meridian at the Diſtance of 6 Hours in Time. If the Sun be in the ſame Part of the Heavens with the Moon, as when ſhe is new, or in the oppoſite Part, as when ſhe is full, the Waters in D and B will thereby be rendered yet lighter, and ſo will riſe higher, and make what are called the *Spring Tides*. The greateſt Height *d* is not under the Moon, but follows her; and D *d* is equal to twice A *a*.

26. If two Bodies of different Kinds of Matter,

Matter, as Braſs and Glaſs, be equipoiſed in the Air, and then weighed together in Water, the Equilibrium will be deſtroyed, and the Braſs will preponderate, becauſe its Bulk being leſs than that of the Glaſs, it will loſe a leſs Part of its Weight, or be leſs reſiſted than the Glaſs, and therefore be heavier in the Water (See *Art.* 16.). And this we confirm by Experiment.

27. Alſo from hence we ſee *the Reaſon in general why any Body ſinks or ſwims in a Fluid.* For ſuppoſe any Body were heavier than Water in the Proportion of 8 to 1, as Braſs; then in the Water, it can loſe but $\frac{1}{8}$ Part of its Weight (*Art.* 14.) and therefore muſt *deſcend* with $\frac{7}{8}$ of the Whole.

28. If a Body, as *Cork*, be lighter than Water in the Proportion of 1 to 4; then it is plain, as there is 4 times as much Weight in an equal Bulk of Water, ſuch a Quantity cannot be raiſed by the *Cork*, and conſequently it *cannot immerſe itſelf, or ſink in Water wholly*; but it will raiſe $\frac{1}{4}$ of its Bulk of Water, as being of equal Weight, and ſo will *ſwim* with $\frac{1}{4}$ Part of its Bulk in the Water.

29. If a Body be of the ſame ſpecific Gravity with the Water, *it can neither ſink nor ſwim.* For if it be immerſed it muſt loſe all its Weight (*Art.* 14.) and ſo cannot deſcend. Alſo it will every-where tend downwards with a Force equal to the Reſiſtance or Preſſure of the Water upwards; and *ſo it will*

not

not riſe to the Top or ſwim. Hence appears the Reaſon, why a Bucket of Water, a Man, or any Animal in Water, ſeems ſo very light, and to have ſcarce any Weight at all. Theſe Phænomena alſo are all illuſtrated by Experiment.

30. Hence the Reaſon alſo of another paradoxical Poſition is evident, viz. *The heavieſt Body placed at a proper Depth in Water ſhall there be ſuſtained by the Water, or kept from ſinking though left freely to itſelf.* To prove this by Experiment, let *a b c d* be a Piece of Braſs, which by means of a String is drawn tight againſt the Orifice of the Glaſs Tube *a f g b* (with a Piece of wet Leather at *a b* to keep out the Water) in this Caſe it is plunged more than 8 times its Thickneſs *e b* under Water in the Jar A B C D; and the String being there let go, the Braſs does not deſcend or ſink, but is ſuſtained by the

31. For the Preſſure upwards againſt the Surface *d c* is equal to the Weight of a Column of Water *d h i c*, whereas the Preſſure downwards is equal only to the Weight of the Braſs, or 8 times the Bulk of Water, *e b*, which, as it is leſs than the former, ſhews plainly enough that the Braſs cannot ſink at any Depth greater than 8 times its Thickneſs (ſee *Art.* 18. and 19.) In the ſame Manner it is ſhewn by Experiment, that a Piece of *Cork* will not riſe or ſwim in *Mercury* if it be kept from preſſing it upwards on its under Surface.

32. Hence

32. Hence alſo the Reaſon of another *Phænomenon*, which uſed to be thought ſtrange, *viz. that the ſame Body ſhall ſink in one Fluid and ſwim in another.* Thus, a Piece of Braſs will ſink in Water, but as readily ſwim in Quickſilver; becauſe it is *heavier than Water* in the Proportion of 8 to 1 (by *Art.* 19.) *and lighter than Mercury* in the Ratio of 14 to 8 (by *Art.* 19 and 21.).

33. Next to the *Hydroſtatic Balance*, there is no Inſtrument which owes its Invention to this Branch of Science more uſeful than the HYDROMETER or *Water-poiſe*; it conſiſts of a large hollow Ball or Globe A B D, with a long Stem or Neck A F G; and a Weight at the Bottom B C E, to be ſcrewed on and off at Pleaſure, and ſuch as ſhall be ſufficient to ſink the Inſtrument in any propoſed Fluid, till its Surface ſhall coincide with the middle Point F in the Neck.

34. Suppoſe the Stem A G divided into 20 equal Parts, and the Weight C B ſo adjuſted as to ſink the Hydrometer in *Rain-Water* (which is the lighteſt of all Waters) to the middle Point F, then if it be immerſed in any other Water, it will not deſcend ſo deep in it, by which means that Water will be found to be heavier. And thus in general, all Kinds of medicinal Fluids, mineral or other Waters, may be examined as to their Gravity or Denſity. Indeed an exact Eſtimate or Compariſon of the reſpective

tive Gravities of Fluids may be made by this Inſtrument, but that is better done by the Hydroſtatic Balance.

35. Again, the Strength of all ſpirituous Liquors may by this Inſtrument be very eaſily diſcovered and compared. Thus, if pure Spirit of Wine be poured to an equal Quantity of Water, it makes what we call *Proof-Spirit*; then if the Weight B C be ſuch as will ſink this Inſtrument in this Proof-Spirit to the middle Point F, or tenth Diviſion in the Stem; if you put it into any Spirits that are weaker, it will not ſink ſo deep, becauſe of the larger Proportion of Water which is heavier than Spirit. On the other hand, if it be immerſed in Spirits that are above Proof, it will ſink deeper than the Point P; and ſo in all Caſes it may be readily and certainly known, whether any Sort of Spirit be above or below Proof *.

36. Another very curious Uſe of this Inſtrument is, *to find immediately if Money be good, or any ways debaſed or diminiſhed.* To this End, inſtead of the Weight B C, I ſcrew on a Piece ſo contrived as to have a Piece of Money affixed to it inſtantly; and ſuppoſing that to be a *Guinea of George* III. the Whole is ſo adjuſted as to ſink in common Water to

* I have lately made a new and moſt accurate HYDROMETER in Braſs, which will ſhew any Degree of Strength in ſpirituous Fluids to the 1000th Part of the Difference between Water and pure Spirit; with a Treatiſe deſcribing its Uſe.

the

the Point F; but if a faulty Guinea be put on, no Part of the Stem will be immerſed, nor the upper Part of the Body; whence the Fraud is eaſily diſcovered. And thus it may be accommodated to examine any other Species of Money. Nay, even all *Degrees of Difference in good Money*, as appears by the Experiment; but the Balance is ſtill preferable for this Purpoſe.

37. The Method of conveying Water by AQUEDUCTS, is the next Thing to be examined; to repreſent this Affair, let A B be a *Reſervoir* of Water, its deſcending Pipe C D; in the Part D there is a Piece F (with a Joint) ſcrewed on, which communicates the Water to the Tube G H affixed to it on the other Side. By means of the Joint at F, this Tube G H may be put into any Situation. Then ſuppoſing E K the *horizontal Line*, and A I parallel to it, you will find that in every Poſition of the Tube, the Water will conſtantly riſe in it to the Level A I, and no higher. Fig. 9.

38. The Reaſon of this is evident; becauſe when a Fluid becomes divided into two Parts, and is at Reſt, there muſt be an *Equilibrium of their Force or Preſſure* againſt each other; but this cannot be but from an *equal perpendicular Altitude* in each Part above the Horizon E K (by *Art.* 5 & 9.) and conſequently as the Height of the Water in the Reſervoir is A E, that of the Water I K in the Tube G H muſt always be equal to it;

it; and there its Surface in every Position of the Tube will ever be in the Line A I parallel to the Horizon E K.

39. If then G H repreſent the main Pipe, which is laid up the Side of a Hill on which a Town is built, it is evident that the Water will be conveyed from this Pipe by the lateral ones to all the Houſes ſituated below the Level A I; but to none above it, from I to H.

40. Let the Figure and Size of the Conduit-Pipe G H I be what it will, the Water will ſtill riſe in it to any Part G or I, be-
Fig. 10. low the Level of that in the Reſervoir A B. And therefore Water may be conveyed over any high Place F G H, as a Houſe, a Mountain, *&c.* Or from the Top of one Hill G acroſs the Vale H to the Top of another Hill I, by means only of a bended Pipe F G H I. Hence the vaſt and expenſive Labour of building *Aqueducts from Mountain to Mountain* is not neceſſary, but where more Water is required than can be carried by Pipes.

41. As the Tube contributes nothing towards the Cauſe of the Water's riſing in it; ſo if the Tube were away, and a ſmall Piece or Adjutage G were affixed to the Part F with a little Hole in the Top, the Water would riſe through that Hole in *a Jet*
Fig. 11. *d'Eau* or *Fountain* G I, nearly to the Height of that in the *Reſervoir* A B. But becauſe there is ſome Coheſion in the Fluid, ſome

ſome Attraction and Friction in paſſing thro' the Hole, a conſiderable Reſiſtance from the Air, and the Weight of the Water above impeding the Aſcent of that below, we find the Jet can never poſſibly riſe to the full Height of the Reſervoir which ſupplies it.

42. The Operation of the Syphon C F E is eaſily accounted for by the Preſſure of Water in Conjunction with that of the Air. For ſuppoſe the Syphon filled with Water, and inverted with its ſhorter End in a Glaſs of Water A B, then if there were no Preſſure of Air to affect the Water, the Water in the Syphon would immediately ſeparate in the higheſt Point F, and run down from thence in each Leg towards C and E, and ſo there could be no Operation at all. Fig. 12.

43. But as there is a Preſſure of Air conſtantly acting upon the Surface of the Water in A B, it will cauſe Water to riſe from C to F; for ſince the Preſſure of Air is the ſame on both Orifices C and E, and the Leg F E is the longeſt, there will be a greater Weight of Water at E than at C, and conſequently the Water in the Leg F E will run out; and if we ſuppoſe the Water to part at F, there muſt be a Vacuum in the Syphon at F, which is impoſſible while the Water at C and E is under the Preſſure of the Atmoſphere. It muſt therefore be always full till the Surface of the Water in the Jar comes to the Oriſice C, and then no more can be preſſed up.

It is eaſy from what has been ſaid to ſee, that if the external Leg were F D equal to F C, or if the two Orifices of the Syphon C, D, were in the ſame horizontal Line C D, the Water could not move through it.

44. Hence alſo the *Phænomenon* of the *Tantalus Cup* is eaſily underſtood; for if a Syphon be bent in the Form of a Handle C D E, and fixed into the Side of a Mug or Cup A B, ſo that the Orifice C may communicate with the Cup near the Bottom, and the Orifice E be a little below it; then, upon pouring Water into the Cup it will riſe in the Handle at the ſame Time; and when in the Cup it comes to the Height F, ſo as to be upon a Level with the higheſt Part D of the Handle, the Water will then deſcend through the other Part D E, and run out without ceaſing at E, till the Water deſcends in the Cup to the Orifice C.

Fig. 13.

45. Hence we ſee the Reaſon why ſome Ponds and Wells loſe or diſcharge all their Water in a ſurpriſing Manner as ſoon as they are filled, by ſome *analagous ſubterranean Duct or Syphon*. Alſo the Reaſon of *intermitting Springs*, which are ſupplied by a Syphon, and which can only run when that works. Alſo thoſe called *reciprocating Springs*, as they are ſupplied by a conſtant Stream, cannot intermit; but if at the ſame Time they receive Water from an *intermitting Syphon or Duct*, the Surface of their

their Waters will riſe and fall in *correſpondent Reciprocations*. Of all which we have an admirable Inſtance in that Spring called *Laywell* near *Brixham* in *Devon*, whoſe Water ebbs and flows juſt *ten Times* every Hour.

46. The *Antiguggler* has ſometimes its Uſes, and therefore it is uſual to ſhew it by Experiment: It conſiſts of a ſmall curved Tube, which is to be put into the Neck of a Bottle or Vial, that ſo while the Liquor is running out, the Air may enter through the Tube without ruſhing thro' the Body of the Liquor (which makes the uſual *Guggling*) and thereby diſturb the Sediment, and foul the Liquor.

47. We come now to the moſt uſeful Part of *Hydroſtatics*, which concerns *Pump-Work*; and the Reaſon of the Operation of PUMPS in general, will be eaſy to underſtand from the foregoing Principles. A *Water-Pump* is every way like an *Air-Pump*, conſiſting of a Barrel, a Piſton, and two Valves; all which are here of the ſame Uſe as there, but made of different Materials. The Form of the common Pump is repreſented in the Figure, in three Parts; the firſt is the Ciſtern A B, into which the Water is brought by the Piſton K L, which plays in the ſecond Part or Barrel D E; and the third Part is the Pipe or Tube F G, which goes down to the Water in the Well or Veſſel H I. Fig. 14.

48. In the Bottom of the Barrel there is a

Hole, over which is placed a *Leathern Valve* to move up and down; and the ſame Sort of Valve there is in the Bucket L of the Piſton, which has alſo a Perforation to let the Water paſs thro' it. Theſe Valves open upwards, and permit the Water to riſe; but prevent its Return by ſhutting down cloſe upon the Holes beneath. The Bucket L is lined with Leathers, to make it fit the Inſide of the Barrel very nicely, that ſo none of the Water above may get into the Part below; and to *fetch the Pump*, as they call it, or to make the Water riſe, they firſt pour Water into the upper Part over the Bucket to make all tight.

49. Then the Piſton, being ſuppoſed at the Bottom of the Barrel at E, is raiſed up from thence to Q by the Handle K M; then is the Air contained in the Tube F G expanded into the large Space of the Barrel from E to Q, and conſequently has its Spring leſſened; it will therefore preſs with leſs Force on the Water contained within it, than the Air preſſes on that without; hence the Water muſt riſe in the Tube to ſome Height O, till its Weight, and the Spring of the Air within, be equal to the Preſſure of the Air without.

50. When the Piſton is forced down, the Air beneath riſes thro' the Bucket; and that in the Pipe above O, when the Piſton is raiſed, is expanded again into the Barrel; and its Spring being again diminiſhed, the Water will

will be raiſed to a greater Height P in the Tube. And thus as the Air becomes gradually exhauſted, the Water will riſe higher and higher, till at laſt it will arrive to, and force up the Valve N in the Barrel; and having aſcended thro' it, it cannot return, but muſt, upon the Deſcent of the Piſton, be forced thro' its Valve alſo; and as this Valve alſo prevents its returning, it muſt be raiſed by the Aſcent of the Piſton, into the Ciſtern of the Pump A B, and there run out through the Spout C.

51. Any Pump of this Conſtruction will raiſe Water to any Height not exceeding 32 or 33 Feet. For ſince the Water riſes, and is ſuſtained in the Pump by the *Preſſure of the Air*, and ſince this Preſſure is equal to the Weight of a Column of Mercury 29½ Inches high (Sect. III. 31.) it will be equal to the Weight of a Column of Water 14 Times as high (*Art.* 21.) therefore $29\frac{1}{2} \times 14$ makes 413 Inches or $34\frac{7}{12}$ Feet nearly, which is the Height to which the Water would riſe in a Pump, if all the Air could be perfectly exhauſted. But as no Pump of this Kind is or can be made ſo Air-tight as to do that, the Water never riſes ſo high.

52. The Pipe ſhould be of ſo large a Bore as to admit the Water into the Barrel ſo freely, as to follow the Piſton without leaving any Space between; for unleſs the Water be in

Contact with the Piſton below, there is much more Force than the Weight of the Water above it to overcome in each Stroke; and ſo the Labour of Pumping will be greatly increaſed.

53. If there were no Hole or Valve in the Piſton, but a Valve opening outwards in the Side of the Barrel near the Bottom, then the Machine would become a *Forcing-Pump*; for every Aſcent of the Piſton would raiſe the Water into the Barrel, and every Deſcent would force it through the *lateral Valve* into ſome Pipe or Duct, to any Place or Height you pleaſe.

54. There are various Contrivances in the Form and Conſtruction of Pumps; ſome of which are very curious, as particularly the *Mercurial Pump*, ſo called by Reaſon the Exhauſtion or *Vacuum* is here effected by Quickſilver, inſtead of the common Piſton. And this Method is eaſily applicable at large, and without any great Expence. It is capable of producing the Effect of a Pump in the greateſt Perfection, as all muſt allow who ſee the Model and the Experiment upon it.

55. There is alſo another very uſeful Invention of this Kind, *viz.* A *portable Pump*, and which works by a Piſton, indeed, but without any *Friction:* The Piſton plays wholly in Water, and does not touch the Sides

Sides of the Veſſel in which it is contained. The Stroke in this Pump is very ſhort, and it may be uſed as an *Exhauſting*, a *Lifting*, or a *Forcing-Pump*. The Mechaniſm is very ſimple and eaſy to be underſtood by the Model; and the Rationale of its working by the Experiment.

57. There is another very ingenious Invention in *Hydraulics*, to ſhew how a *Water-Mill may be contrived without Wheels* to grind Corn, by a moſt ſimple Structure, and with a ſmall Stream of Water. The Model of this Machine is as follows. A B is the Ciſtern receiving the Stream or Spout of Water which from thence deſcends by the Tube C D into the Horizontal Trunk E F; this Trunk has two Holes in it on the oppoſite Sides at the Ends, as G at the End F; and another on the oppoſite Side at the End E. Thro' theſe Holes the Water ruſhes out, and by that Means turns round the Machine in a retrograde Manner, or in the Direction F L E M. In the lower Part of the Trunk is fixed a ſtrong Iron Shaft or Axis I K, which at K turns upon a fine Point in a Pivot Hole in the lower Part of the Frame N O P Q; and on the upper Part P Q is fixed a ſmall circular Piece *a b*, repreſenting the nether Mill-ſtone; above there is another *c d*, which being fixed to the Axis I K in the Center I, is thereby turned very ſwiftly round upon Fig. 15.

the other; and thus is the End of a Mill by this Means anſwered.

58. The Reaſon why the Machine muſt move round very ſwiftly, will eaſily appear, if we conſider, that if the Trunk had no Hole in it, the Preſſure of the Water within would be the ſame on every Part, and proportional to the Height B D; but if a Hole be made at G, the Preſſure of the Water on that Side and End is diminiſhed; and the Preſſure being greater on the other cloſe Side, will therefore cauſe that End to begin a Motion from F towards I; and a Hole being made on the oppoſite Side at the End E, will double the Cauſe, and conſequently the Velocity of the Machine. It is plain, the Force to turn the Machine is proportional to the Height of the Water B D, and the Diſtance of the Hole G from the Center of the Machine conjointly.

59. *Newſham's* WATER ENGINE is rather a *Pneumatical* than a *Hydraulic Machine*; but I ſhall explain it in this Section. The Deſign of it is to produce a *continual Stream of Water*, and to project it to *great Diſtances*; this is done by Means of *two Forcing Pumps*, which alternately compel Water into a large cloſe Veſſel of Air; the Air is thereby gradually condenſed, and compreſſes the Water beneath with ſo great Force, that upon turning a Stop-Cock on the upper Part, it ruſhes out with great Impetuoſity

ſity through a Pipe that comes down into it, and makes a continued Stream, by the Air's being continually condenſed and acting conſtantly upon it.

60. To illuſtrate this, let A B C D be be a Glaſs Globe or Veſſel, filled about half full with Water B C D; upon the Top is ſcrewed a Stop-Cock E, with a Pipe H F going to the Bottom of the Water. On the upper Part, at I, is firſt ſcrewed on an *injecting Syringe*, by which the Air is thrown in, and greatly condenſed in the Part B A D; then turning the Cock, you take off the *Syringe*, and ſcrew on the *Ball* and *Socket* I G; thro' which, upon opening the Cock, there will iſſue a continual Stream G K with great Velocity, by the Action of the Air compreſſing the Water B D. Fig. 16.

61. In the ſame Manner a Variety of *Jet d'Eau's*, and pretty Devices of that Kind, may be practiſed upon this Inſtrument, by ſcrewing on different Pieces upon the Top of the Cock, particularly if the Veſſel be large, a Piece may be ſcrewed on at I, very full of exceeding ſmall Holes, thro' which the Water may ſpout obliquely, and form an *artificial Shower of Rain*; in which when the Sun ſhines ſtrongly, a Rainbow will plainly appear, if your Back be turned to the Sun, and you view the falling Drops againſt a *black*

Wall or *Cloth*. And this Experiment, well managed, infallibly confirms the Theory of the Rainbow, as deduced from the *Doctrine of Light and Colours* in SECT. II. 22. 30.

SECTION

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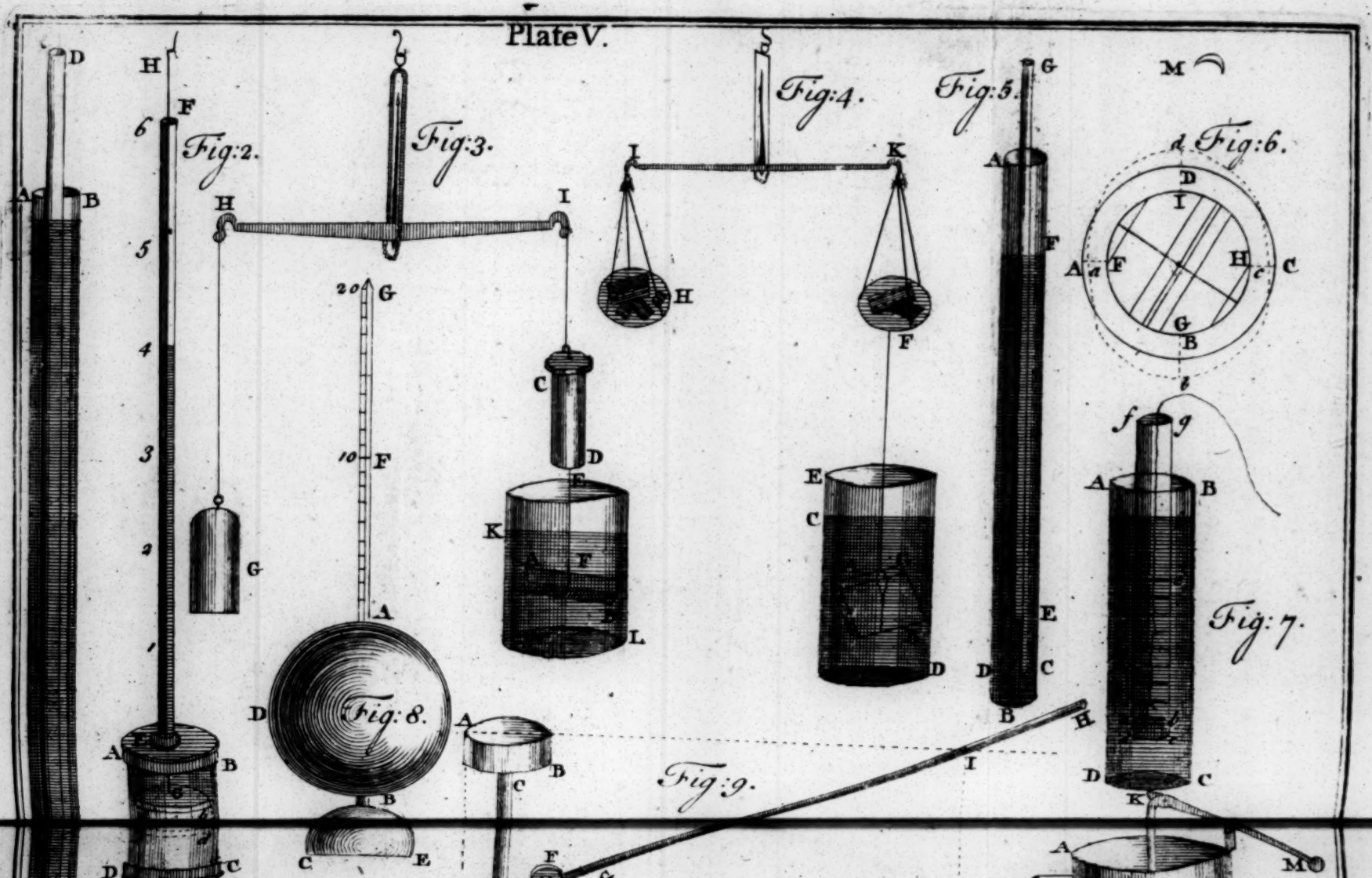
Plate V.



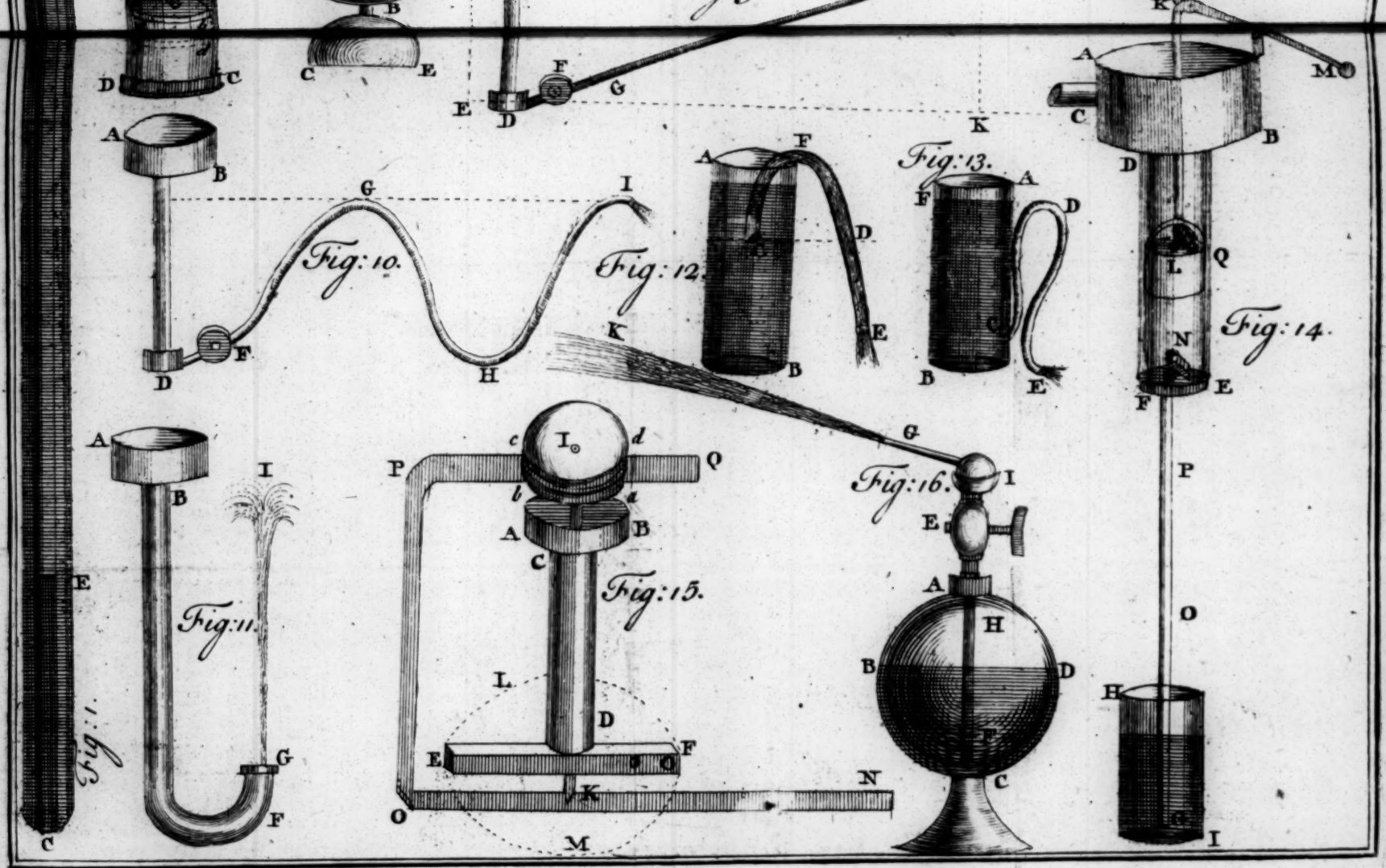


Fig: 1.
Fig: 10.
Fig: 11.
Fig: 12.
Fig: 13.
Fig: 14.
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Fig: 16.

SECTION VI.

Of MOTION *and* REST. *The* LAWS *of* MOTION *explained. Of the* Compoſition *and* Reſolution *of* Forces. *The Nature and Uſe of* PENDULUMS *explained. A new* PYROMETER *deſcribed to meaſure the* Expanſion of Metals. *Of the* CENTERS *of* Magnitude, Motion, *and* Gravity. *Of the* common Center of Gravity *in the Syſtem of the Heavenly Bodies. The* Principles *of* MECHANICS *explained. Of the ſeveral* Mechanical Powers; *the* LEVER, *the* WHEEL *and* AXLE, *the* PULLEY, *the* INCLINED PLANE, *the* WEDGE, *and the* SCREW. *The* ſtrongeſt ARCH *to build upon. The Doctrine of* WHEEL CARRIAGES, *&c.*

1. THE Subject of this Section will be to conſider the *Nature, Laws*, and *Phænomena* of MOTION, and *moving Bodies*; the Nature and Uſe of *Pendulums*; the *Center of Gravity*; the *Theory of Mechanical Powers* and *Machines*; and the Doctrine of *Wheel Carriages*; and to demonſtrate each Particular by Experiments.

2. MOTION

2. MOTION is the *Change of Place* in Bodies; and *Reſt* is their *Continuance in the ſame Place*. The moſt general Cauſe of Motion with us, is that Power in the Earth and other Bodies we call GRAVITY, by which they attract, gravitate, or move towards one another, unleſs hindered by ſome intervening Obſtacle; and indeed this is the Cauſe of all Motion in the larger Bodies of the Syſtem.

3. There is beſides this an *Animal Cauſe* or Power of *producing Motion* in Bodies. For any Animal can, at Will, move any Body in any Direction, provided that his *Muſcular Force* be not inferior to the *Force of Gravity* in that Body; and where this happens to be the Caſe, we have Recourſe to Art; and by Means of many Kinds of Mechanical Contrivances, we are enabled to raiſe and move ſuch heavy Bodies as far exceed our *natural Strength*. And hence we derive the moſt uſeful Science of MECHANICS, or *Conſtruction of Mechanical Powers and Machines*.

4. The Manner in which we conceive the Idea of Motion, makes it neceſſary to diſtinguiſh it into two Kinds; *viz.* *Real* and *Apparent*; for we may not only have an Idea of Motion in Bodies when they do *really move*, but alſo when they *do not move*, but are abſolutely at Reſt. This Ambiguity in our Ideas of Motion renders us ſubject to many and very great Miſtakes in our common

common Notions or Judgment of Things. Nor are theſe Errors of an indifferent Nature, but oftentimes greatly concern the Well-being of Mankind, not only in regard to the Sciences, but even to *Religion* itſelf: Witneſs the Caſes of thoſe who are anathematized for denying the diurnal Motion of the Sun and Stars; as that of poor *Galileo* in the Inquiſition, about 100 Years ago.

5. That we may be able therefore to judge truly of Motion, we muſt conſider, that the Idea is produced in the Mind *by the Paſſage of the Image of Objects over the Retina in the Bottom of the Eye.* Hence then, if the *Eye be at Reſt*, what Ideas we have of Motion muſt in that Caſe be of *true or real Motion*; for nothing but Motion in the Object here can produce a Motion of the Image in the Eye. But, on the other hand, it is as evident, that *if the Eye be in Motion*, an Object before it, though at Reſt, will have its Image move over the Retina, and ſo produce a *deceptive Idea of Motion.*

6. Hence, with reſpect to the Motion of Bodies, there will be three Caſes. For (1) *The Eye may be at Reſt, and the Object in Motion* (as above) which is the only Caſe in which we can have an Idea of the *true and real Quantity of Motion.* And even in this plain Caſe we are liable ſometimes to be deceived, *viz.* When the Motion is ſo very quick

quick as not to admit of any ſenſible Intervals of Time in paſſing over ſenſible Intervals of Space. Thus we ſee no Motion of the Particles of Light in the *Sun-Beams*; thus alſo a Body may be turned ſo ſwiftly as not to appear to move at all; and a *Red Spot* whirled ſwiftly round makes a *Red Circle* without Motion. All which is evident from common Experience.

7. The Second Caſe is, *when the Object is at Reſt, and the Eye in Motion*; and here, as the Motion is altogether apparent, the Idea we have of it, muſt be the moſt of all illuſive and deceitful. But the Errors of this Sort are often ſo very groſs and obvious, that we can correct them by the leaſt Degree of Reaſon; thus to a Perſon in a Ship under Sail, looking out of the Cabbin-window, the Houſes and Trees on the Shore appear to move; but no Man was ever ſo irrational as to think ſuch a Motion real. In the ſame Manner, if our Earth does really turn upon its Axis in 24 Hours *from Weſt to Eaſt*, it muſt neceſſarily cauſe an *apparent Motion of the Sun, Moon, and Stars*, in a contrary Direction, *viz. from Eaſt to Weſt*, in the ſame Time.

8. The Third Caſe is, *when the Eye and Object are both in Motion*; and this may be ſubdivided into three other Caſes. As (1) When the Eye and Object both move the *ſame Way, and with equal Velocity*. In this Caſe,

Caſe, it is plain, the Image of the Object muſt always retain the ſame Place or be at Reſt on the Retina, and conſequently no Motion of the Object can be perceived. Hence the Ships under Sail ſeem *at Reſt* to a Perſon ſhut up in the Cabbin; and we on the Surface of the Earth perceive nothing of its diurnal Motion.

9. Again (2) The Eye and Object may move the ſame Way with different Velocities. In this Caſe the Object will appear to *move with the Difference of the two Velocities*, viz. *forwards*, if its Velocity be greater than that of the Eye; or *backwards*, if leſs. Thus if two Ships A and B ſailed both the ſame Way, A at the Rate of 3 Miles an Hour, and B at 5; if you were in A, the Ship B would appear to *go forwards* from you at the Rate of 2 Miles *per* Hour; and if you were in B, the Ship A would appear to go backwards or the contrary Way, as faſt, while the Ship you are in ſeems quite at Reſt.

10. If (in the 3d Place) the Eye and Object both move, *but in contrary Directions, or meet* each other, then the Object would appear to *move with the Sum of the two Velocities*. Thus ſuppoſe the two Ships A and B meet each other, each ſailing with the Velocities above-mentioned, then a Spectator placed in either of them, would ſee the other approach him with a Velocity of 8 Miles *per* Hour. And hence it appears that unleſs

unleſs we are well apprized of the true State and Circumſtances of Bodies which appear to move, or not to move, both in reſpect of them and ourſelves, it is impoſſible the Judgment we form of their Motion ſhould be correct, but very precarious, and moſtly full of Illuſion and Error.

11. VELOCITY is the *comparative Swiftneſs* or *Slowneſs* of Bodies in Motion. Thus if the Ship A ſail at the Rate of 3 Miles *per* Hour, and B at the Rate of 5 Miles *per* Hour, they are ſaid to move with Velocities which are to each other as 3 to 5.

12. The *Momentum, Force,* or *Quantity of Motion* in moving Bodies, is all that Power they have to *act upon,* or affect each other in *Colliſion,* or any Object by ſtriking againſt it. And this depends upon *two Things,* (1) The *Quantity of Matter* in Bodies; and (2) the *Velocity of their Motion.* For it is eaſy to underſtand that when two Bodies move *with equal Velocities,* there can be nothing to make a Difference in the Force of their Strokes, but the *different Quantities of Matter* they contain. Thus a Globe of Gold, and another of Braſs, of equal Bulks and Velocities, will ſtrike with Forces which are as their Quantities of Matter or Weight, *viz.* as $17\frac{1}{2}$ to 8. (See Sect. V. 19.) Thus 100 lb. Weight will ſtrike with 100 Times the Force of 1 lb. moving with the ſame Velocity.

13. Secondly,

13. Secondly, on the other hand, if the *Quantity of Matter continue the ſame*, it is as plain the Force of the Stroke will be exactly proportional to Velocities of Motion. Thus a Bullet projected from the Hand, will not do the Execution as it would if ſhot from a Gun; becauſe of the much greater Velocity in the latter Caſe. And therefore the *Quantity of Motion* in any moving Body is to be eſtimated by its *Quantity of Matter*, and *by its Velocity* conjointly; and therefore it is always as the Product of one multiplied by the other.

14. To illuſtrate this important Article, it is to be noted, that if any Body B ſuſpended by a String A B, and raiſed to any Diviſion of the circular Arch E D, and there let go, *it will, by its Deſcent to the loweſt Point* D, *there acquire a Velocity that will be proportional to the Arch of Deſcent, and therefore may be meaſured by it*. That is, if a Body deſcend from the Points B, C, E, the Velocities acquired by thoſe Deſcents will be in the Point D, as the Arches B D, C D, and E D reſpectively. Fig. 1.

15. Therefore let the Body B of 3 Ounces, deſcend from the 5th Diviſion, and ſtrike the Obſtacle D, and afterwards let it deſcend from the 9th Diviſion, to ſtrike the ſame Obſtacle, then will the Magnitude of the Strokes be as the Velocities, *viz.* the Force of the firſt Stroke to that of the ſecond as 5 to 9. Fig. 2.

16. But

Fig. 3. 16. But if the Ball B of 3 Ounces deſcend from the 5th Diviſion, and another Ball G of 2 Ounces deſcend from the 9th Diviſion, the Stroke of B will be to that of G, as 3 Times 5 or 15, to 2 Times 9 or 18. And thus, I preſume, the Nature of Force or Momentum, or Quantity of Motion, is very eaſy to be underſtood from what has been premiſed.

17. Sir *Iſaac Newton* has conſidered all the Affections of Motion under *three general Heads*, which he calls the *three Laws of Motion*, and ſometimes they are called the *Laws of Nature*, becauſe they are obſerved by all Bodies whatſoever. The firſt of theſe is, *That every Body endeavours to continue in a State of Reſt, or moving uniformly in a right Line, unleſs ſo far as it is compelled to change that State by Forces impreſſed.*

18. This is evident by conſidering, that each Particle of Matter is abſolutely inert and paſſive, and ſo quite indifferent to Reſt or Motion; and if it chance to be *at Reſt*, ſince it has no Principle of Action in itſelf, it cannot of itſelf change that State; and for the ſame Reaſon, if it be once in Motion, it muſt neceſſarily ſo continue, all Obſtacles being ſuppoſed away. The Motion likewiſe muſt be in a right Line, there being nothing in Matter itſelf to alter that Direction of Motion which it had in the Beginning.

19. Thus

19. Thus then it appears that all the Change that is at any Time made in Bodies is by the Action of external Force impreſſed. Bodies at Reſt, without being acted upon by external Objects, we can eaſily conceive, will always remain at Reſt. And it is as true, that Bodies in Motion, where there is no reſiſting Medium or Obſtacle, will preſerve their Motions undiminiſhed; witneſs the *Planets* and *Comets*. But the Ball on the Billiard-Table, or the Bowl on the Green, it is evident, loſe their Motion only by the Reſiſtance of the Plane or Parts on which they move. If the Axis of a Wheel in Motion were to move on other moveable Wheels, the Motion would continue much longer; becauſe Parts in Motion afford not the Reſiſtance to Bodies as when they are fixed; again, if the Axles of theſe moveable Wheels were to move on the Peripheries of other moveable Wheels, the Reſiſtance or Friction would be ſtill farther diminiſhed, and the Motion of the firſt Wheel would be continued much longer. And if the Friction could be diminiſhed *ad infinitum*, the Motion would become *perpetual*; all which we illuſtrate by Experiments on a *Machine of Friction-Wheels*.

20. Hence it evidently follows, that a *perpetual Motion* is abſolutely impoſſible to be effected by any human Art or Contrivance; becauſe no Machine can be conſtructed with

a Motion of the Parts one upon another, and conſequently not without Friction, which will by Degrees deſtroy all the Motion communicated to the ſame by any Agent whatſoever. We alſo hence ſee the Reaſon why the *Planets* and *Comets* continue to move with their original Velocities undiminiſhed; as they are Bodies vaſtly large, moving very ſwiftly, in free or unreſiſting Mediums.

21. The *ſecond Law of Motion* is, the *Change of Motion is always proportional to the moving Force impreſſed; and is always made according to the right Line in which that Force is impreſſed*; that is, *a double Force* will produce *a double Quantity of Motion*; *a triple Force, triple that Quantity*, and ſo on. Thus if the Body A, by an Impetus from another Body B, were moving in the Direction A D; and at the Inſtant it was at A another Force were impreſſed upon it by the Body C in the Direction A F; then a Change would be made in the firſt Motion of the Body A, *both in regard of its Velocity and Direction.*

Fig. 4.

22. For ſuppoſing by the Stroke of B the Body A would deſcribe the Space or Line A D in one Second of Time; and that by the Stroke of C it would deſcribe the Line A F in the ſame Time, then it is plain by both Forces together, it muſt proceed with a Velocity greater than either ſingly, and in a Direction which is compounded of both the others: For draw F E parallel to A D, and

and D E parallel to A F, interſecting each other in E, and join A E, and that Line A E ſhall be the Direction which the Body A will purſue by this compound Motion; and the Space A E will be deſcribed by it in the ſame Time as A D or A F by the ſingle Impulſes of B, or C.

23. For the Force impreſſed by C does not at all alter its Velocity of approaching to the Line D E, and therefore at the End of the given Time it will be formed in that Line; for the ſame Reaſon, by the Force of C, it will arrive to, and be formed in the Line F E; and therefore at the End of the given Time, it will be found in the Point E, common to both, after it has deſcribed the Line or Space A E.

24. Hence the moſt uſeful Doctrine of *the Compoſition and Reſolution of Forces* is derived. For any two Forces may be repreſented or eſtimated by two Sides of a Parallelogram A D E F analogous to them; and then the Diagonal will expreſs the Force compounded of both. Alſo, on the other Hand, any given Force A E may be reſolved into two others A D, A F, acting in different Direction, according to which there may ariſe a great Variety of Caſes, *which I have elſewhere explained* *.

25. The *third Law of Motion* is, *that Action and Re-action between Bodies are equal and in contrary Directions.* For ſince the

* *Philoſophia Britannica.*

Impact or Stroke between the two Bodies is but one ſimple individual Thing, it can affect both of them but in one and the ſame Manner and Degree, or they muſt act upon or affect each other mutually and equally thereby. If a Horſe draws a Stone by Means of a Rope, all the Force by which they act upon each other, is expreſſed in the *Tenſion of the Rope*; but that is the ſame throughout, and therefore equal at each End, upon the Horſe and upon the Stone.

26. The Queſtion is, then, if the *Horſe and Stone act equally on each other, how it comes to paſs that the Horſe can move the Stone?* The Anſwer is eaſy, *viz.* Becauſe tho' there be *an Equality of Action*, there may not be *an Equality of Force* between the Horſe and Stone; for when that is the Caſe, there can be no Motion in ether. Thus ſuppoſe the Muſcular Force of the Horſe were juſt equal to 500lb. Weight; if a Stone of that Weight was faſtened to a Rope, and hung over a Pulley to gravitate freely; the Horſe could not put it into Motion, but there would be an *Equilibrium* of Forces between them. But if the Stone weighed only 400lb. then it could only by *Re-action* deſtroy 400 out of the 500lb. in the Horſe, and the Difference of 100 lb. in the ſuperior Force of the Horſe would put the Stone into Motion. As, on the other Hand, if the Stone weighed 600 lb. it would

draw

draw the Horſe backwards with the ſuperior Force or Difference of 100 lb. Weight.

27. Thus when inanimate Bodies act upon each other by Attraction, or any other Force, they are equally affected thereby; the Loadſtone and Iron are equally acted upon by the magnetic Power. Two magnetic Needles equally attract, and produce equal Quantities of Motion in each other; the ſame is to be underſtood of the Earth, and a Stone falling upon it; in all theſe Caſes, what is wanting in Velocity is compenſated in Quantity of Matter, ſo that one multiplied into the other always make on each Side an equal Force (See *Art.* 12, 13.).

28. On this Principle it is that *Fiſhes ſwim*, and *Birds fly*, and *Men row a Boat*; becauſe when the Medium is acted upon by the *Fin*, *Wing*, or *Oar*, in any one Direction, by an equal *Re-action*, it moves the Fiſh, the Bird, and the Boat, in a Direction juſt the contrary. Though I can't help thinking, that, beſides this *mechanical Action or Power*, there is ſomething of an innate Energy in all thoſe Animals by which they move very ſwiftly, with ſcarce any ſenſible Motion of the Fins or Wings. And this ſecret Power it is in Spiders, by which they fly in any Direction they pleaſe, without any external *viſible Means* at all.

29. I have already obſerved, that a Body falls towards the Earth by the Power of Gra-

vity; and ſince that Power acts conſtantly upon it, its Velocity muſt be *conſtantly accelerated*; and ſince near the Earth's Surface, the Action of Gravity may be ſuppoſed uniform, there will *in equal Times* be equal Increments *of Velocity*, and therefore *the Velocity of falling Bodies will be always proportional to the Time of the Fall.* Hence it is, that ſince the Space deſcended through increaſes both with the Velocity and Time of the Fall, it muſt be *proportional to the Square of either.* Therefore it being well known by Experiment, that a Body will deſcend through 16,2 Feet nearly in one Second, it will in two Seconds fall thro' 4 Times 16,2 Feet, or 64,8 Feet; and in 3 Seconds, thro' 9 Times 16,2 or 146 Feet nearly; and ſo on for any other Number of Seconds.

30. Let B C E be an *inclined Plane*, then if any Body be laid on the higheſt Part B, it will deſcend to the loweſt Point C by the Power of Gravity; and for the ſame Reaſon, if the Body were ſuſpended by a String from any Point A, and the Plane taken away, it would then alſo deſcend in the Arch of a Circle B C to the loweſt Point C; but it will not there reſt, but the Velocity which it has there acquired in the Deſcent will carry it from C to D on the other Side, ſo that the Arch C D is nearly equal to B C; from thence it will again return to B, then back again to D, and ſo on till all the Mo-

Fig. 5.

tion

tion be gradually deſtroyed by the Reſiſtance of the Medium, and the Friction at the Point of Suſpenſion A. A Body vibrating forwards and backwards in this Manner, is called a PENDULUM.

31. If the Pendulum AB be very long, and the Arch B D through which it vibrates very ſmall, the *Times of the Vibrations will be nearly equal*; and hence it came to be applied to *Clock-Work*, for the Regulation of the Movements, which are deſigned to divide the larger Portions of Time into ſmaller equal Parts. And for this Purpoſe it would be the beſt Inſtrument ever yet invented, were it not for one Thing, *viz.* the *Lengthening* and *Shortening* of the Metalline Rod, with which they are made, by *Heat* and *Cold*; for as the Pendulum, by Heat, becomes longer, it vibrates ſlower, and the Clock *loſes Time*; as on the contrary being ſhortened by Cold, it vibrates quicker, and the Clock goes *too faſt*; ſo that a Clock can never make a true or equal Diviſion of Time unleſs the Pendulum continues of the ſame Length, and vibrates in equal Times.

32. To ſhew that Metals expand by Heat, and contract by Cold, an Inſtrument called the PYROMETER has been invented, and contrived in various Forms. Among others, I ſhall give one of my own, which I judge to be the moſt ſimple Structure of any extant. It is repreſented in *Fig.* 6. where Fig. 6.

A B is the Baſis; at one End of which is a braſs Frame C D, in which are contained two Wheels, one large one E, and another ſmall one F, on their Axles. At the other End is fixed a large and ſtrong upright Piece of Iron I K. The Bar of Metal for the Experiment is G H; one End of which is fixed on the Iron Bar by Means of a Hole at K, and the other End H is laid on the Axle of the Wheel E; the Bar of Metal is heated by the Candles placed underneath on the Pedeſtal L. By this Means it will increaſe in Length, and turn the Axle and its Wheel E, which is connected by a String to the ſmall Wheel F; and which being moved, carries the Index P over a large graduated Circle M N O, by which the Quantity of Expanſion may in different Metals be eſtimated as follows.

33. Suppoſe the Bar G H extend in Length only *One Ten Thouſandth Part of an Inch*, this will move the Axle of the Wheel E juſt ſo much about; and ſuppoſe the Diameter of the Wheel ten Times that of the Axle, the Surface of the Wheel E will be moved juſt *One Thouſandth Part of an Inch*. As this Wheel is connected with the ſmall Wheel F, that Wheel F muſt be moved juſt ſo much likewiſe: And now, in the laſt Place, let us ſuppoſe the Diameter of the Wheel F to be $\frac{1}{10}$ Part of the large graduated Circle M N O; then ſince the Index P moves on the Axle of the ſmall Wheel, it will

will move over 20 Times the Space as the Surface of that Weel does in the ſame Time, that is, it will move over $\frac{20}{1000}$ of an Inch, or *One Fiftieth Part of an Inch*; which is viſible to the Eye. And ſo this Machine, tho' ſmall, will ſhew the Extenſion of Metals to be the *Ten Thouſandth Part of an Inch*.

34. If the Bar G H be made red hot, and laid on, it will be ſeen how much it will be contracted or ſhortened when cold. If Bars of different Metals of the ſame Size were heated with the ſame Candles, in the ſame Time, it would eaſily appear what Difference there is in the expanſive Power of the ſeveral Metals. This Inſtrument might alſo be uſed as a *Thermometer*, to meaſure the various Degrees of Heat; it might begin where *Fahrenheit*'s ends, and be eaſily reduced to his Scale.

35. But laſtly, perhaps no Inſtrument can be contrived ſo much for the Purpoſe of an HYGROMETER as this; for if the Bar G H be a long Slip of Wood (*Deal* or *Elm*, for Inſtance) cut acroſs the Grain, and glued together end-ways, and be laid on this Machine as before, with a Piece of Metal on the under Side, and a ſmall Weight above where it lies on the Axle, then the *Moiſture of the Air* will make it expand, and Dryneſs will contract its Length, both which will be ſufficiently ſhewn by the Index P on the large Circle M N O.

36. There

36. There have been different Methods contrived to remedy this natural Defect of Pendulums, two of which I ſhall here mention. The firſt is of the Invention of Mr. *Graham*, and depends on this Conſideration, that any Rod A B ſuſpended and put into Motion is as much a Pendulum as a common One conſiſting of a Wire and Bob C D. And if the Rod or Bar A B be of a *uniform Figure* throughout, it will vibrate in the ſame Time with a Bob-Pendulum C D, which is juſt two Thirds of its Length. The Center E, therefore, in the Rod, which is oppoſite to the Center of the Ball D, is called the *Center of Oſcillation*. If therefore A B be a Braſs Tube filled with Quickſilver, the Tube itſelf, by Heat, will lengthen downwards, but the Column of Mercury in it will be expanded upwards; and ſo, ſince A E is double E B, the Mercury will riſe upwards more than the Tube lengthens downward, it is plain the Center of Oſcillation E may by this Means be kept nearly at the ſame Diſtance from the Point of Suſpenſion; and ſo the Time of Vibration will be more equable, or nearly the ſame in different Degrees of Heat and Cold.

Fig. 7.

37. The Point E is alſo the *Center of Percuſſion*, or it is that Point in which the Forces of all the Particles of the Rod are united in ſtriking; *ſo that a Stroke made from*

th

the Point E *is greater than any other that can be made from any other Point in the Rod.*

38. The other is a *French* Invention, and conſiſts of a Kind of compound Pendulum as follows. A B is a Rod of Iron, in which on the upper Part is a fixed Piece A C; in this is faſtened a Piece of Copper C D, which on its lower End bears on the End of a Lever D E, moveable on the Center B in the End of the Iron Rod; from the End of the Lever E, there hangs the Ball of the Pendulum F. Now ſince Copper will extend with Heat conſiderably more than Iron, the Point D of the Rod C D will puſh down the End of the Lever D, and by that Means raiſe the Weight F upwards; and conſequently, if every Part could be truly adjuſted, the Center of Oſcillation of this Pendulum might always be in the ſame Place, and ſo the Clock keep Time *. Fig. 8.

39. It is well known by Experiment, that a Pendulum which vibrates Seconds is 39 $\frac{1}{3}$ Inches long; alſo that *the Lengths of Pendulums are as the Squares of the Times of Vibration*; therefore a Pendulum that vibrates in half a Second muſt be $\frac{1}{4}$ Part of 39 $\frac{1}{3}$ or 9 $\frac{8}{16}$ Inches long. And by ſuch a Pendulum we can eaſily *meaſure the Diſtance of a Cloud*

* But for a great Variety of curious Inventions of this Kind, ſee a Treatiſe of Clock-work in the GENERAL MAGAZINE OF ARTS AND SCIENCES.

when it thunders and lightens. For holding ſuch a Pendulum in the Hand, as ſoon as you ſee the *Lightening*, let it go, and tell the Vibrations it makes till you hear the *Thunder*, you have then the Number of Half-ſeconds, for every one of which you muſt allow 571 Feet, and then will the Diſtance of the Cloud be known in Feet preciſely. For by many Experiments it has been found, that Sound goes thro' 1142 Feet uniformly in every Second of Time. In the ſame Manner the Diſtance of a Ship on the Sea may be meaſured by the *Fire and Report* of a Gun.

40. The Pendulum has been of Uſe alſo in helping to diſcover the *true Figure of the Earth*; for a Pendulum that vibrates Seconds here, will vibrate more than 60 Times in a Minute, under the polar Circle, and leſs than 60 under the Equator; and as this Difference is greater than what could ariſe from Heat and Cold, it was rightly concluded to be owing to a different Power of Gravity on the Pendulum in thoſe Places, occaſioned by the different Diſtances from the Center of the Earth. This gave Occaſion for an actual Menſuration of a Degree under the Equator and Polar Circle, by which it appeared *that the Diameter of the Equator exceeded the Axis of the Earth by* 80 *or* 90 *Miles*; and that therefore *the Earth is not a Sphere, but an oblate Spheroid.*

41. In

41. In a mechanical Conſideration of Bodies, there are three Sorts of Centers that offer themſelves to our View, *viz.* the *Center of Magnitude, Motion, and Gravity*. The *Center of Magnitude* is that Point in any Body which is equally diſtant from all the external Parts of that Body. The *Center of Motion* is that Point in the Surface, or that Line in a ſolid Body that remains at Reſt, while all the other Parts of the Body move about it. And the *Center of Gravity* is that Point which being ſupported, the whole Body is ſupported, or kept from falling. The Manner of finding this Point in any Body, is beſt ſhewn by Experiment.

42. If two or more Bodies are connected together, or any how depend on each other, as by Attraction, *&c.* there is always a *common Center of Gravity* between them. Thus for Inſtance, let E and M be the Earth and Moon, and C their *commom Center of Gravity*; the Diſtance thereof E C from the Earth, is to the Diſtance C M from the Moon as the Quantity of Matter in the Moon is to that in the Earth, which is nearly as 1 to 40, and therefore allowing the Diſtance of the Moon from the Earth to be 240,000 Miles, the Diſtance E C will be a little more than 1800 Miles. And it is this Center C, that both the Earth and the Moon continually revolve about. And alſo it is the ſame Center C (and not the Center of the Earth) that Fig. 9.

that deſcribes the annual Orbit about the Sun. There is alſo a like common Center of Gravity between the *Sun and all the Planets*, and about which the Sun as well as all the Planets revolves. So that, truly ſpeaking, there is no Body in the whole Syſtem at Reſt, or the Center of Motion to others.

43. Any Machine or Inſtrument is called a *mechanical Power*, by which we are enabled to raiſe or move ſuch heavy Bodies as exceed our natural Force or Strength; and this may be done two Ways, *viz.* by *encreaſing the Power which acts againſt the heavy Body*; or, Secondly, *by diminiſhing the Weight of the Body*. The Power is increaſed by increaſing the *Velocity of Motion* (*Art.* 13.) And there are three Sort of Machines which do this, *viz.* the *Lever*, the *Pulley*, and the *Wheel* and *Axle*. And the Weight of Bodies is diminiſhed, or their Action againſt the Power leſſened, by laying them on an *inclined Plane*, to which we refer the *Wedge* and the *Screw*.

Fig. 10. 44. The LEVER is an inflexible Line or Rod AB moveable about a Point C, on which it is ſupported, and is called the *Fulcrum*; at different Diſtances from this Point at each End are applied the Weight W, and the Power P, which are in Equilibrio with each other. Now whenever the Lever is put into Motion, it is evident, the Velocity of the Power will be to that of the Weight

Weight as the Diſtance CB to the Diſtance AC; and therefore the Quantity of Matter in P will be leſs than that in W in the ſame Proportion. And therefore *ſo much are the natural Powers of Bodies increaſed by this Machine.*

45. The PULLEY, being only a Wheel, is ſingly no *mechanical Power*, becauſe Bodies ſuſpended upon it have *equal Velocities of Motion*; but a Combination of two or more Pullies conſtitute a *mechanical Machine*. For it is evident the Velocity of the Power P is greater than that of the Weight W, in proportion *as the Number of Ropes belonging to the lower Set or Box of Pullies exceeds Unity*. Thus in the Figure the Weight W hangs by five Ropes, and the Power P by one, therefore, when the Weight is raiſed one Inch, the Power will deſcend through five; and its Force is therefore increaſed five Times. Fig. 11.

46. I ſhall juſt here remark, that a *juſt Ballance* is in the Nature of a *ſingle Pulley*; and a *falſe Balance is like the Lever*; and yet the *Steel-yard*, which is a Lever alſo, is a *juſt Ballance* when truly made, and one of the beſt Inſtruments of this Kind. The Nature of the Ballance, eſpecially the *falſe one*, will be fully illuſtrated by Experiments.

47. The WHEEL and AXLE is a very uſeful *mechanical Power*; becauſe the Power P hanging from the Circumference Fig. 12.

CD

C D of the Wheel, will have a Velocity greater than that of the Weight W on the Axle, *in proportion as the Diameter of the Wheel is greater than that of the Axle*, that is, of 12 to 1, in the Figure. Of this Kind are all *Winches*, *Windlaſſes*, *Capſtans*, *Crane-Wheels*, &c.

48. The INCLINED PLANE is a *mechanical Power*, by diminiſhing the Weight of Bodies laid thereon. For, let the Plane be A B, and D E F a Body lying upon it, this Body will gravitate in the Direction of the Line N H, perpendicular to the Horizon B C, and cutting the Plane in G. Suppoſe therefore the Line N G repreſent the whole Gravity of the Body, draw N F perpendicular to the Plane; then will the whole Gravity N G be reſolved into two Parts N F and F G (by *Art.* 24.) but ſince the Part NF is perpendicular to the Plane, it will be all deſtroyed by the *equal Re-action* thereof (*Art.* 25.) and ſince the other Part F G is parallel to the Plane, it will tend to move the Body down upon it.

Fig. 13.

49. Now this *reſidual Gravity* (which is all we have to overcome in moving Bodies up the Plane) is to the *whole Gravity* of the Body as G F to G N, or as G H to G B, that is, as A C to A B, *viz. as the Height of the Plane to its Length*; and therefore the more the Plane is inclined to the Horizon, the leſs will be the Weight of Bodies lying on

on them, which we act againſt; and conſequently the greater will be the Advantage of this Machine.

50. The WEDGE, A B C, muſt certainly be a *mechanical Power*, as it conſiſts of *two inclined Planes*, joined by their Baſis. But though the Plane is doubled in the Wedge, yet the Force of the Wedge is not *double*, but only *equal to that of a ſingle* Plane A C, or B C; for each Plane acts againſt equal Forces by the fixed Baſe D C, common to them both. And *therefore the Force of the Wedge is ſtill expreſſed by the Proportion of* A C *to* A D, viz. *the Length of the Side to half the Thickneſs*. Of this Kind is the *Knife*, the *Axe*, the *Chiſel*, &c. Fig. 14.

51. The SCREW A B is generally reckoned a *ſimple mechanical Power*, but very miſtakenly, ſince we never work it without the Lever F G, or ſomething analogous to it. This Machine, when rightly conſidered, is nothing but an *inclined Plane, coiled round a Cylinder*; and as a heavy Body is raiſed only through the perpendicular Diſtance of two Threads while it has paſſed once round the Cylinder, therefore, *the Power is to the Weight* (in this Machine alone) *as the Diſtance of the Threads* to the *Circumference of the Cylinder*; that is, *as the Height to the Length of the Plane*, as before. Fig. 15.

52. But, as I ſaid, ſince to this Machine we generally add the Lever, they become

together a Machine of very great Force, and not only ſerves in many Caſes for moving or raiſing Weights, but its Make adapts it to anſwer all the uſeful Purpoſes of *Compreſſion*; and for *holding and binding Bodies together*. And perhaps there is not a Machine ſo univerſally neceſſary in every Buſineſs of Life as the *Screw*.

53. The Computations of Force in the foregoing Machines, is upon Suppoſition that there is *no Friction between the moving Parts*; but as no Machine can be contrived without it, and when ſeveral are combined together into one compound Machine, it is found, that a very conſiderable Allowance muſt be made for it; *viz.* near a *third Part of a whole acquired Force*, muſt be allowed to overcome the Friction of the ſeveral Parts. This being done, the Force of any compound Machine is known, by *multiplying together the ſeveral Forces of all the ſimple Powers of which it conſiſts*.

54. If a Chain be ſuſpended at each End, upon the Points A C, it will by its Weight ſettle itſelf into a Curve A B C, called the *Catenaria*; and, ſince all the Parts of this Curve are in Equilibrio by their mutual Gravity, it is evident, that it is preferable to any other for the *Form of an Arch to build upon*. For, if this Curve be inverted, or turned with its convex Part upwards, it will ſupport itſelf. And it is demonſtrated

Fig. 16.

that

that when the Height of the Arch D B, and its Thickneſs at Top B E, are given, then there will be an Equilibrium in all Parts, *When the Half-length of the Chain* A B *is a Mean proportional between the Height* D B *and the Sum of the Height, and twice the Thickneſs* B E. That is, when D B : A B : : A B : D B × 2 B E. Fig. 17.

55. In the laſt Place, with reſpect to WHEEL CARRIAGES, we may eaſily underſtand, that a large Wheel G H I will go over any Obſtacle with more Eaſe than a leſſer one B C D. For, ſuppoſe B E an Obſtacle placed before the low Wheel, and equal in Height to the Radius or Semidiameter O D, then, if the Wheel be drawn in the Direction A B, parallel to the Horizon E I, it is plain the Point of the Wheel at B will be drawn directly againſt the Top of the Obſtacle, and alſo its Center O; and ſo the whole Motion of the Wheel will be deſtroyed by the equal Re-action of the Obſtacle B E, ſuppoſed to be fixed. But the ſame Obſtacle being placed before the larger Wheel at E G, the Point G in the Wheel is below the Center Q, and conſequently, when the Wheel is drawn horizontally, the Point G preſſes the Obſtacle obliquely, and ſo only a Part of the Force is deſtroyed by Re-action; the other remaining Part will tend to raiſe the Wheel over the Obſtacle. Since, then, a high Wheel will go over an Obſtacle, Fig. 18.

Obſtacle, when a low Wheel will not; it follows, *they are moſt advantageous for Carriage.* And this we ſufficiently ſhew by Experiments, *in loading Waggons before and behind*, &c.

Fig. 19. 56. Another Contrivance for facilitating the Draft of loaded Carriages, is, by placing a Box E F, containing two *moveable Wheels*, A B, C D, over the Ends of both Axle-trees, in ſuch Manner, that the End G of the Axle may lie in the Interſection of the two Wheels; and therefore, when the Waggon is loaded, it will bear wholly by theſe Friction Wheels on the Axles; and when drawn along, the Friction Wheels will move with the Axles, by which Means the Friction, or Reſiſtance in the common Way, is abated nearly in the Proportion of the Diameter of the Friction Wheel to that of the Axle. All which will appear very plainly by Experiments made on a Carriage of this Sort.

F I N I S.

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Plate VI.

Fig:1.

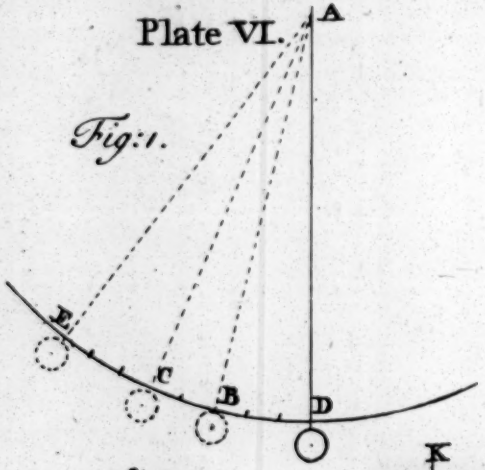


Fig:2.

Fig:3.

Fig:4.

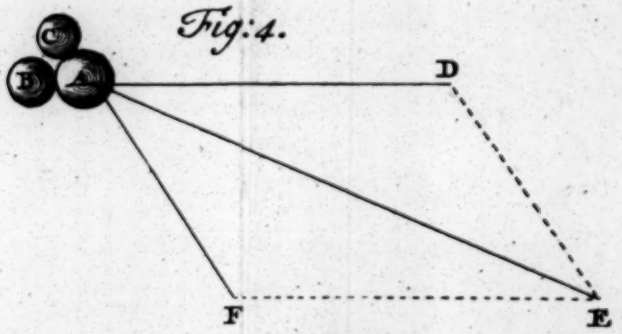


Fig:5.

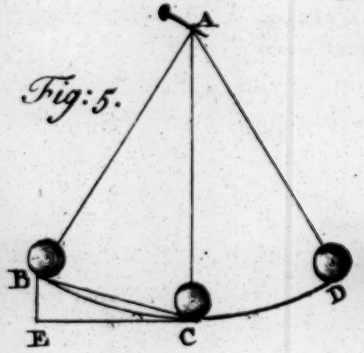
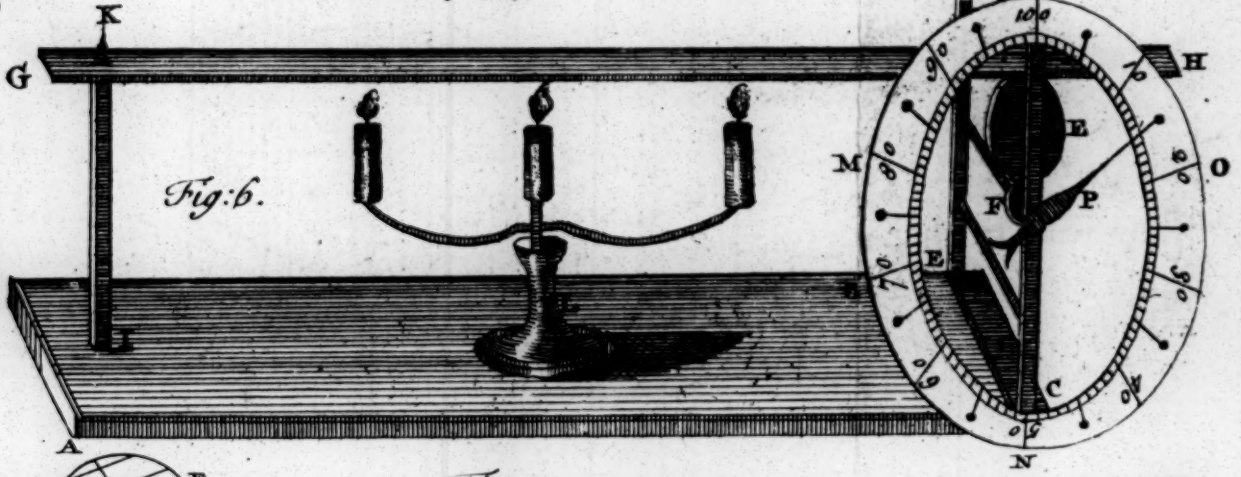


Fig:6.



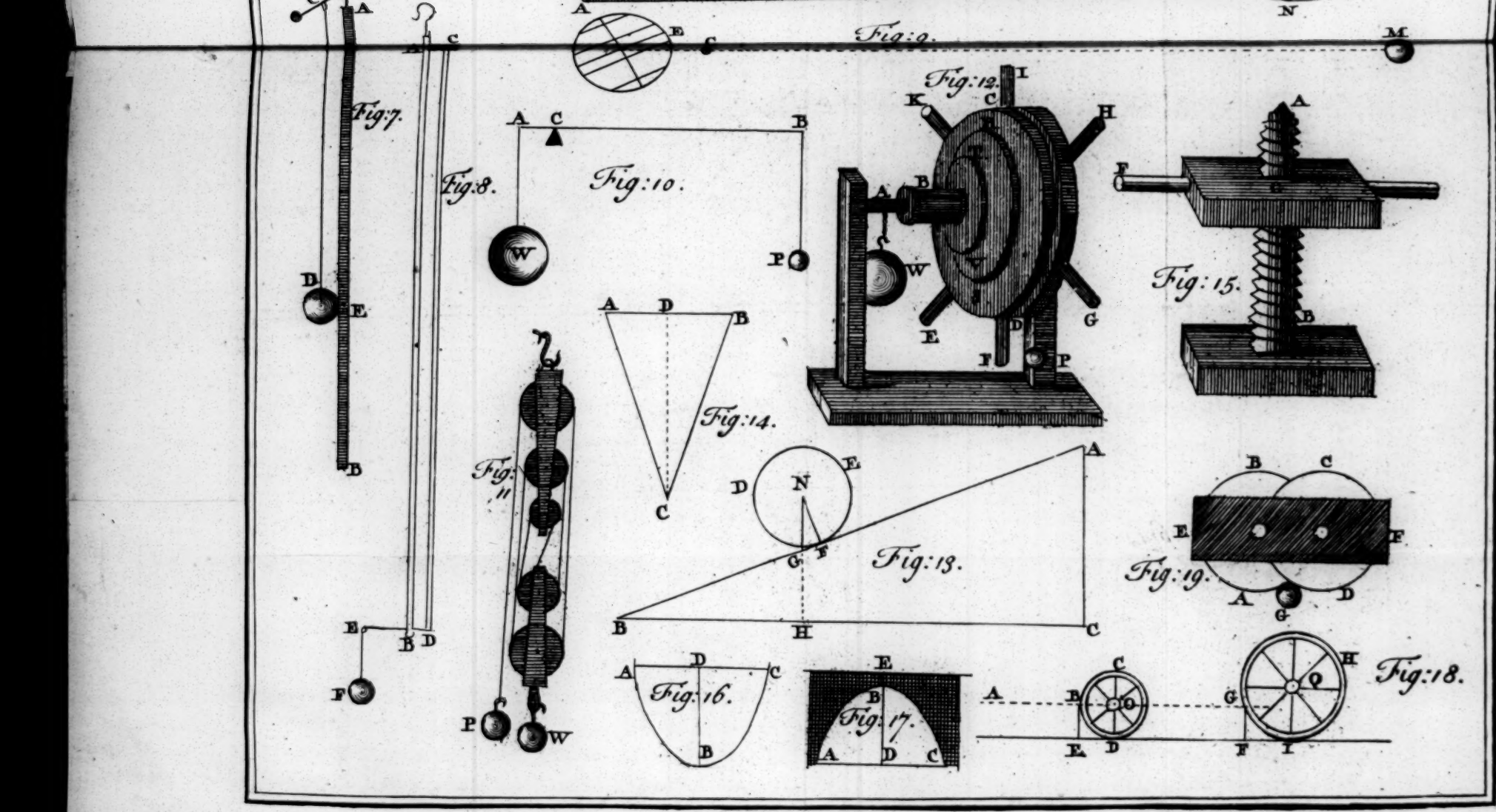


Fig:7.
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